Business Models for Second-life Electric Vehicle Battery Systems

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This dissertation is submitted for the degree of ***Doctor of Philosophy***

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To my loving parents and my grandmother.

Declaration

I hereby declare that this dissertation is the result of my own work and includes nothing which is the outcome of work done in collaboration except as declared in the Preface and specified in the text.

It is not substantially the same as any that I have submitted, or, is being concurrently submitted for a degree or diploma or other qualification at the University of Cambridge or any other University or similar institution except as declared in the Preface and specified in the text. I further state that no substantial part of my dissertation has already been submitted, or, is being concurrently submitted for any such degree, diploma or other qualification at the University of Cambridge or any other University or similar institution except as declared in the Preface and specified in the text.

This dissertation contains less than 65,000 words with 31 figures and 29 tables. It does not exceed the prescribed word limit for the Engineering Department Degree Committee.

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Abstract

Innovative Business Models (BMs) are essential in commercialising new technologies that are initially seen as inferior. Battery second use (B2U) brings used batteries from an electric vehicle (EV) into a secondary storage application and holds the potential to improve the sustainability of EVs while generating value for stakeholders across the automotive and energy sectors, as well as for the environment and society (Gohla-Neudecker et al. 2015; Neubauer et al. 2015). However, important knowledge gaps exist as the potential value of second-life batteries and how to better extract that value are still poorly understood by both practitioners and researchers.

To fill the knowledge gap, this study explores the BMs of repurposing a second life for the retired EV batteries through rich empirical case studies. The main outcomes of the research are firstly, a deeper understanding of the sustainable value of second-life batteries as is currently being achieved by industry, which also provides a comprehensive view of the potential value of B2U. Secondly, the critical B2U challenges are identified from a multi-stakeholder's perspective across the value chain that present a fresh overview of the key factors that might impair the potential value of B2U. Thirdly, an empirically-generated typology of existing B2U business models is proposed that shows how B2U stakeholders are interacting in different ways to create and capture value from B2U. Fourthly, three critical BM design elements, namely, lifecycle thinking, system-level design and the shift to services are proposed as helpful aspects for B2U stakeholders to consider to better design their B2U business models. Fifthly, Business Model of a Technology (BMoT) is proposed as a new perspective to understand the value potential of second-life batteries and how to maximise the total value creation from B2U at the system level.

The research has filled a literature gap, has met an industrial need, and has made contributions to knowledge on sustainability and BMs in the specific context of B2U. Practically, the findings have the potential to inspire practitioners toward better understanding the potential value of second-life batteries and improve their BMs to better extract value from B2U.

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List of Abbreviations and Acronyms

BMs	Business Models
B2U	Battery Second use
BOL	Beginning-of-Life
BMoT	Business Model of a Technology
BEVs	Battery Electric Vehicles
BMS	Battery Management System
B2C	Business-to-Customer
B2B	Business-to-Business
CBM	Circular Business Model
EMS	Energy Management System
EOL	End-of-Life
ELVs	End-of-life Vehicles
EVs	Electric Vehicles
GWh	Gigawatt-Hour
KWh	Kilowatt-Hour
MOL	Middle-of-Life
NiMH	Nickel Metal Hydride
OEM	Original Equipment Manufacturer
PSS	Product-Service System
PV	Photovoltaic
SOH	State of Health
SOC	State of Charge
TWh	Terawatt-Hour
TCO	Total Cost of Ownership
TBL	Triple Bottom Line
V2G	Vehicle-to-Grid
VPP	Virtual Power Plant

1 Introduction

1.1 Research background

In the last few decades, manufacturing firms have been facing great challenges including resource scarcity, soaring prices of energy and materials, environmental pollutions and societal pressures (Evans et al. 2009). Those challenges have forced firms and governments to reflect on the traditional linear growth models and adopt circular economy thinking to decouple growth from scarce resource use (Ellen MacArthur Foundation 2012). The circular concept requires companies to become more involved in the use and end-of-life (EOL) phases of a product, in addition to its production and selling. Adopting the circular economy thinking enables companies to regenerate value from extending a product's life cycle and create value not only for their customers and partners, but also for the society and environment (Lacy & Rutqvist 2015). A circular economy model provides a promising approach to increased sustainability for society (Ellen MacArthur Foundation 2012), but it is also not that easy to implement.

Academia and practitioners have a new enthusiasm for studying the logic of value exchange which they call business models (BMs). The traditional "sell-and-disengage" model is argued to be increasingly under strain and innovative BMs such as retaining the ownership of products which incorporate life-cycle social and environmental impacts are beginning to be adopted by some manufacturing firms (Planing 2015). In the past decades, there is a growing interest to both academia and practitioners in building BMs that introduce sustainability into the core of the business (Stubbs & Cocklin 2008; Boons & Lüdeke-Freund 2013; Johnson & Suskewicz 2009). The advance towards BMs for sustainability extends the conventional view of a BM creating value for customers and shareholders, to the value creation for a wider range of stakeholders including society and environment (Schaltegger et al. 2016).

The automobile industry is regarded as one of the least sustainable systems (Nieuwenhuis & Katsifou 2015), which also offers a fertile terrain for innovation, especially with the introduction of alternative powertrain technologies (Zapata & Nieuwenhuis 2010). Electric vehicles (EVs), which have attracted increasing attention in the recent decade, hold great promise for a more sustainable transport in the future (IEA 2013). Some governments have committed to incorporate EVs into their strategic plan and set ambitious goals for the automotive sector. For example, Britain has announced a ban on all new petrol and diesel cars and vans from 2040, following a similar pledge in France.

The wide adoption of EVs is still restricted by the high initial cost of EVs, which in part results from the core and most expensive component of the powertrain: the battery (Neubauer & Pesaran 2011). Over time, when the batteries are no longer able to provide sufficient power and range for EVs due to their aging characteristics, there will be millions of tons of batteries coming out of the cars. If not properly treated, those retired batteries could place tremendous burdens on the environment.

An EV battery reaches its EOL in vehicular service due to capacity fade, either before or coinciding with the vehicle's EOL. In general, an EV battery has 70–80% of its original capacity intact upon reaching the end of its vehicular life (Neubauer & Pesaran 2011), and replacement is recommended in order to satisfy the range demand of EV owners (Cready et al. 2003). Battery recycling is currently one of the crude options for the future of retired EV batteries. However, upon retirement there would still be sufficient capacity left in the batteries to support less demanding applications such as load shifting, renewable energy storage and back-up power (Wolfs 2010; Viswanathan & Kintner-meyer 2011; Neubauer & Pesaran 2011; Beer et al. 2012; Knowles & Morris 2013). It would be a huge waste of resource, energy and R&D investment that went into the manufacturing of the batteries to just recycle them instead of repurposing a second life for the batteries to extract more value.

Compared with recycling which entails costs, wastes, as well as energy and material losses, recapturing the residual value from the retired EV batteries could generate alternative revenue streams to help overcome EV cost-hurdles (Brett D. Williams & Lipman 2010), create synergic value for energy storage (Gohla-Neudecker et al. 2015) and bring substantial social and environmental benefits (Neubauer et al. 2015). Major automotive companies such as Nissan, BMW and Daimler have started initiatives to investigate or even commercialise second-life batteries. This research explores the case of repurposing second-life EV batteries for energy storage applications.

1.2 Problem statement

The concept of repurposing retired EV batteries or battery second use (B2U), as we call it throughout the thesis, holds the potential to improve the sustainability of EVs while generating value for stakeholders across the automotive and energy sectors, as well as the environment and society (Gohla-Neudecker et al. 2015; Neubauer et al. 2015). However, the potential value of second-life batteries and how to better extract that value are still poorly understood by both practitioners and researchers. Literature providing an understanding of the value of B2U with supporting empirical evidence is rare. Bräuer (2016) addressed the need of more research into innovative BMs to help overcome the challenges of B2U. The lack of B2U business model research based on industrial cases hinders in-depth understanding of what is happening in the B2U industry, how companies are developing BMs to create and capture value from second-life batteries, as well as the application of existing knowledge to help better develop BMs for second-life batteries. There is thus a gap in our knowledge (explained in detail in Chapter 2) and this study aims to fill this gap and increase understanding of this topic.

There is also an industry need to develop effective BMs to help companies better extract value from B2U. Companies are aware of the potential benefits provided by B2U, but they are also facing a lot of challenges which make it difficult for them to create and capture value from second-life batteries. There is a lack of knowledge and expertise in industry on the potential value of second-life batteries and how to develop BMs that better extract the value.

Interestingly, the Environment Bureau of the Hong Kong Government organised an *International Competition on Second Life for Retired Batteries from Electric Vehicles* in June

2017 to help find innovative ideas for the second-life of retired EV batteries. This indicates the industrial and even policy need to address this emerging problem and also justifies the value and novelty of this research.

1.3 Research objective

This research starts with a real-world problem and aims to draw insights from empirical evidence to make contributions to knowledge that could in turn be applied to practice. The objective of this research is to **develop a better understanding of the potential value of second-life batteries and how firms could improve their business models to better extract that value**. This research objective is to address the problem identified thereby making both theoretical and practical contributions to the fields of BMs and sustainability in the specific context of B2U.

1.4 Research questions

To achieve the research objective described above, the main research question proposed is:

How could firms develop battery second use business models based on sustainability concepts to achieve the potential value of second-life batteries?

The main research question can be decomposed into three key elements: a) better understanding the potential value of second-life batteries and the challenges that might prevent the value extraction; b) better understanding current BMs for second-life batteries; and c) better understanding the incorporation of sustainability into BMs that helps achieve the potential value of second-life batteries. Therefore, this research will answer the following three sub-questions:

1) What are the challenges for B2U and what is the potential value of second-life batteries?

2) How are firms creating and capturing value from second-life batteries through their current BMs?
3) How can firms better develop BMs that draw on sustainability concepts to achieve the potential value of second-life batteries?

These research questions are proposed based on the research problem identified as well as a comprehensive literature review, and are shaped by the researcher's philosophical position discussed in Chapter 3.

1.5 Thesis structure

This thesis comprises seven chapters and the design of the thesis is shown in Figure 1.1. The figure presents the aim of each chapter and the outcomes to deliver after each chapter.

Chapter 1 aims to present an overview of this research. It introduces the background of the research, the research problem identified and the research objective. The research questions are proposed and thesis structure illustrated.

Chapter 2 aims to ground the research context in the existing knowledge and identify the research gap in the literature. In this chapter, the relevant literature is reviewed and gaps in knowledge addressed which also validates the novelty of the proposed research questions.
Chapter 3 aims to present the research design and explain the logic behind that. It illustrates the researcher's philosophical position, the research methodology, as well as the research method selection.

Chapter 4 aims to present each of the seven case studies and investigate initial findings through single-case analysis. It provides the empirical evidence for this research.

Chapter 5 aims to look across the seven case studies for patterns. It presents an analysis across all the case studies and the patterns and findings that emerge.

Chapter 6 aims to present the author's reflections on the implications of the research findings and discuss the findings in relation to the literature. In this chapter, the case findings are further synthesised and new findings presented. A final framework is also developed to illustrate the key points made in this research. Furthermore, findings are discussed in relation to the existing knowledge and their implications for practice addressed.

Chapter 7 aims to conclude this research and propose future work. It presents an overview of the research and summarises the contributions to knowledge. It also addresses the limitations of this research and opportunities for further research.

Chapter aims		Outcomes
• Provide overview of the research • Guide to the thesis structure	**Chapter 1.** Introduction	• Academic and industrial background • Research objectives and questions • Thesis structure
• Review the research context in existing knowledge • Identify research gaps in the literature	**Chapter 2.** Literature review	• Gaps in knowledge • Validation of research objectives and questions
• Explain the logic of the research design • Select research approaches • Present and evaluate the research design	**Chapter 3.** Research methodology	• Research methods • Research design
• Present the empirical case studies under the research context • Investigate initial findings through single case analysis	**Chapter 4.** Case studies and single case analysis	• Description of the cases • Single case findings from seven individual case studies
• Look across the seven case studies for patterns; • Findings from cross-case analysis	**Chapter 5.** Cross-case analysis and findings	• Cross-case analysis and findings
• Present the author's reflections on the research findings • Build a final framework • Discuss the findings in relation to the literature	**Chapter 6.** Synthesis and discussions	• Cross-case synthesis and further findings • A framework • Contributions to knowledge • Academic and practical implications
• Conclude the research and propose future work	**Chapter 7.** Conclusions	• Research summary • Contributions • Limitations • Future work

Figure 1.1 Thesis structure

2 Literature Review

This research explores how firms develop business models (BMs) to extract value from second-life EV batteries. In the previous chapter, the importance of B2U within the wider context of sustainability was introduced and the research problem presented. This chapter grounds the research in the literature to seek for key fields of knowledge that help investigate the research problem and confirm the presence of a gap in knowledge.

This research explores three fields of literature shown in Figure 2.1: a) sustainability, b) BM and c) battery second use (B2U). The three fields were chosen because they are the most relevant to the research inquiry: how firms develop B2U business models to extract value from second-life batteries? The three fields of literature generate four intersections: BMs for sustainability, B2U for sustainability, BMs of B2U, and BMs of B2U for sustainability. This chapter mainly presents a review of the literature on the three overlapping topics and some important studies in individual fields (red dots). As the research progresses, additional literature is reviewed and supplements the literature covered in this chapter. Through reviewing the current status of literature, the gap in existing knowledge is identified which form the foundation for this research inquiry. Based on the literature reviewed and the gap identified, this chapter confirms the research question.

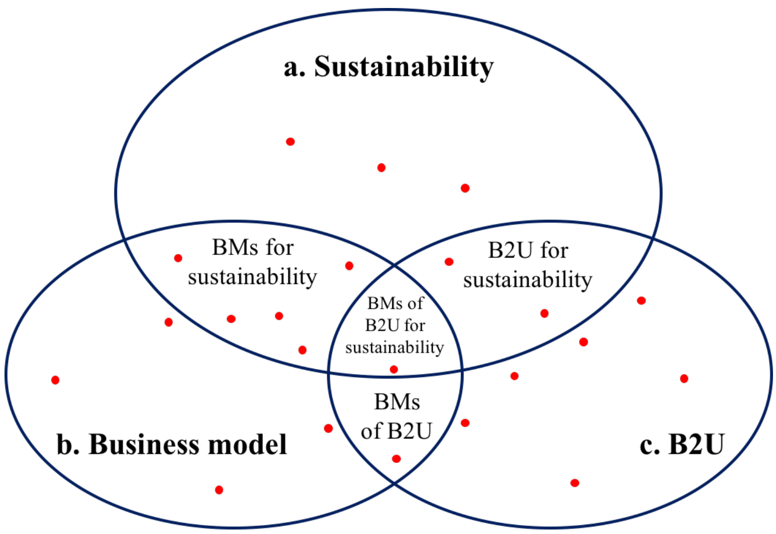

Figure 2.1 Position of the research inquiry in the literature

2.1 How the literature was reviewed

Based on the research problem, the literature review started with some broad reading in the three fields mentioned above. Keywords were coded to help identify the key papers that are most informative of the research problem. Combinations of the initial keywords 'sustainability', 'business models' and 'battery second use/second life/repurpose' were used for the literature search. The bibliographical, peer-reviewed resources (papers and well-cited books) used were: Scopus, Web of Knowledge and the Cambridge University Library catalogues. Non-peer reviewed publications were also studied from sources such as consultancy, corporate and government reports. In the specific area of B2U, very few documents are available at this early stage of the research area. Some of the B2U literature is not peer-reviewed but they are important to understand this new area and are carefully selected and used in this study. The publications were filtered and selected according to their relevance to the research inquiry, their influence (e.g. high citation rate) as well as the novelty and rigour of the studies.

The key papers identified form the starting point of the literature review. Their authors, research projects, journals and conferences were then followed up and the citations from the key papers were investigated. By the use of the snowballing technique, the literature review branched out to include further relevant papers. Some additional keywords (e.g. 'circular business models', 'product-service systems', 'life cycle thinking') were found and used to further explore key themes that might enlighten the research topic. Key academic journals including Journal of Cleaner Production, Energy Policy, Journal of Industrial Ecology, Journal of Power Sources, Business Strategy and the Environment and Long Range Planning were monitored frequently during the research. Further publications are selected using the similar approach.

The study uses the review technique of snowballing because the research inquiry started with a specific problem identified. The aim is to review the important papers in the key fields of knowledge to help investigate the research problem, rather than to review all the literature published in the fields. This method might cause bias in the literature selection due to the author's research preferences and some relevant papers might be missed. To mitigate this weakness, the author continued to update the review: following the key conferences, discussing the work frequently with other researchers, and reading the latest review papers to ensure the comprehensiveness and impartiality of the literature review.

2.2 Sustainability

This section reviews the literature in the field of sustainability. As shown in Figure 2.2, this section includes the important papers that help understand the concept of sustainability (green shadow) but excludes the intersections with BMs and B2U. The literature in the intersections is presented later where the concepts of BMs and B2U are introduced.

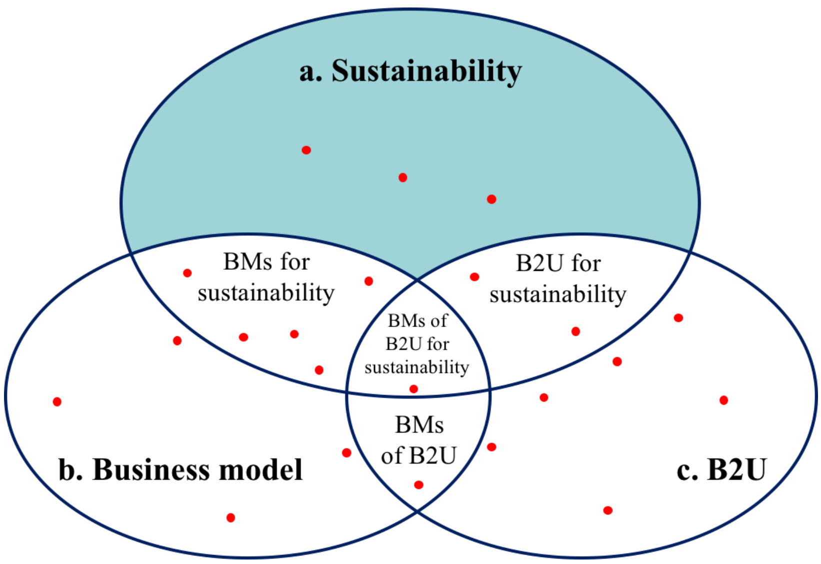

Figure 2.2 Literature review in the field of sustainability

2.2.1 The development of the sustainability concept

There is a pressing need to transform from the unsustainable model of growth-by-depletion to more sustainable sociotechnical systems (WBCSD 2010). The rapid growth of the world population coupled with immoderate ways of production and consumption has caused tremendous social and environmental problems that are jeopardizing the living planet, such as climate change, resource depletion, biodiversity loss and social instability (WWF 2014). How to sustain the human population with the ever-increasing demands on a finite planet is becoming a critical challenge.

The concept of sustainability first appeared in publications in 1713 when von Carlowitz wrote the book *Sylvicultura Oeconomica* that formulated the concept of sustainability in forestry (Geissdoerfer et al. 2017). Widespread sustainable concerns started to appear in books and public events since the 1960s. The Stockholm Conference held in 1972 was the first time the concept of sustainability was discussed and brought to the international stage.

The Limits to Growth, the 1972 report to the Club of Rome, was a significant report that stressed the impact of exponential economic and population growth on finite resource supplies, which is inclined more towards environmental issues (Meadows et al. 1972). Meantime, there are discussions on sustainability from society-based considerations such as wealth distribution. The World Conservation Strategy (WCS) in 1980 published a document that stressed the link between the economy and environment, suggesting that economic growth could be used as a tool to raise awareness of the communities on the environment issues.

Despite the widespread attention to the concept of sustainability, there are lots of debates regarding the integration of sustainability and development (Charter & Tischner 2001). To reconcile the conflicts, the term sustainable development was defined in the *Brundtland Report – Our Common Future* as "development that meets the needs of the present without compromising the ability of future generations to meet their own needs" (WCED 1987, p. 43). This report was as another milestone in the mainstream of sustainability research. It highlighted the economic and political aspects of the development agenda, addressing that sustainable development needs to be considered within the wider scope of economics, industries and policies, in addition to environmental perspectives.

The Rio Conference in 1992 brought the Rio Declaration and Agenda 21. The two documents addressed the link between development and environment, and brought together critical concerns such as economic and population growth, poverty, and climate change. In 2002, the Earth Summit in Johannesburg further paved the way for later research in sustainable development. Since then, the interconnection between social, environmental and economic aspects of sustainable development have been widely discussed in various areas such as manufacturing, ecological economics and policy research. In addition, an increasing number of companies has incorporated sustainability concerns into their businesses. In 2015, the United Nations (UN) adopted the Sustainable Development Goals (SDGs), also known as the Global Goals, which cover a wide range of social and economic development issues such as poverty, health, education, climate change, and environmental degradation. The UN SDGs call for worldwide, collaborative action among governments, businesses and civil society and provide an overarching framework for businesses to shape, steer, communicate and report their strategies and activities about their performance and impact.

In this study, sustainability is taken as humanity's goal of human-ecosystem equilibrium within a finite planet where inter-generational equity is also achieved. Sustainable development is regarded as an holistic approach to reaching this goal of sustainability (adapted from Shaker 2015).

2.2.2 Sustainability in the business world

Sustainable development defined in the *Brundtland Report* (1987) is regarded as a turning point in the sustainability discussion, introducing the term into the political mainstream (Elkington 2004). Since then, the term sustainable development has become a common language used by governments, policy makers and environmentalists. Despite its significance in the understanding of sustainability, however, it still remains to be too vague for the business world and hardly provides any operational value in practice (Charter & Tischner 2001).

To introduce sustainability into the business world and resonate the language with business minds, the concept of Triple Bottom Line (TBL) was coined by John Elkington in 1994 and further articulated in his 1997 book *Cannibals with Forks: the Triple Bottom Line of 21st Century Business* (Elkington 1997). TBL extends the traditional bottom line of profits, return on investment and shareholder value to a broader perspective integrating economic, social and environmental dimensions of performance. The idea behind TBL is that the ultimate success of a corporation should be measured not just by its financial performance but also by its social wealth creation and environmental responsibility (Norman & Macdonald 2004). TBL soon became a widely accepted framework adopted by for-profit, non-profit and government entities alike to evaluate their sustainable performance (Slaper & Hall 2011).

However, in the business world sustainable practices are often attractive when they make financial sense (Kiron et al. 2012; Epstein & Buhovac 2014). To secure long-term competitive advantages, firms need to find the overlap between the direct business interests and the interests of stakeholders including the society and environment (Elkington 2004). Savitz and Weber (2006) proposed that sustainability and the TBL are about "mutual benefits flowing in all three directions" instead of one way benefit to the society or environment which is unrelated to the business. In their book *The Triple Bottom Line*, the authors presented in-depth business examples from various industries and explained the sustainability "sweet spot" where all three interests (economic, social and environment) coincide and blend seamlessly (Savitz & Weber 2006). The book suggested that companies adopting the TBL and occupying the sustainability "sweet spot" should have lasting advantages over its rivals.

Businesses are beginning to realise that adopting practices of sustainability and developing sustainable solutions could generate financial, social and environmental benefits simultaneously (Kiron et al. 2012). Charter and Tischner (2001) described sustainable solutions as "products, services, hybrids or system changes that minimise negative and maximise positive sustainability impacts – economic, environmental, social and ethical – throughout and beyond the life cycle of existing products or solutions, while fulfilling acceptable societal demands". The literature suggests that in order to provide sustainable solutions, business must consider the environmental, social and economic impacts of products and services throughout their life cycle and among multi-stakeholders (Thabrew et al. 2009; Tonelli et al. 2013).

A product's life cycle in general includes the beginning-of-life (BOL) – extraction, design and production, the middle-of-life (MOL) – use and maintenance, and the end-of-life (EOL) – reverse logistics, reuse, recycling, and disposal (Jun et al. 2007). Life cycle thinking goes beyond the traditional focus on production facility and manufacturing processes to include environmental, social and economic impacts of a product over its entire life cycle (Figure 2.3), from raw material extraction and processing, to production, distribution, use, repair and maintenance, and eventually to recycling, reuse, recovery, or final disposal (UNEP/SETAC 2007; UNEP/SETAC 2012).

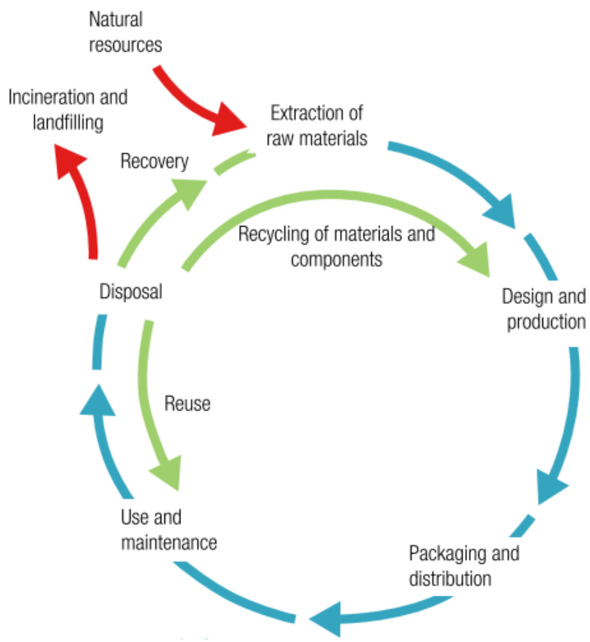

Figure 2.3 A typical product life cycle diagram (UNEP/SETAC 2007)

Life cycle thinking offers a holistic approach to reducing a product's environmental impacts and improve the social and socio-economic performance throughout its life cycle while avoiding potential burden shifting (European Commission 2010; UNEP/SETAC 2012). For example, battery electric cars reduce emissions from fuels burned during vehicle usage phase, but using life cycle thinking, they are shown to increase electricity consumption which is usually generated by polluting sources such as coal, and increase chemical emissions during the manufacture of the battery itself. Hawkins et al. (2013) compared the life cycle environmental impact of EVs and conventional vehicles and found that while in-use emissions decrease by replacing combustion engines with battery powertrains, production impacts are more significant for EVs than conventional vehicles. Moreover, the environmental impacts of EVs are sensitive to factors including energy source for production, use phase electricity consumption and vehicle lifetime. This paper suggests that life cycle thinking in this context should include a focus on reducing vehicle production supply chain impacts and promoting clean energy sources. Life cycle thinking is identified as important for all products and is argued to be even more important for EVs, for example to avoid problem-shifting into the electricity sector.

The literature suggests that companies taking a first-mover position in using life cycle thinking for their products or services will have a wide range of benefits not only in terms of cost reduction and revenue generation, but also less quantifiable benefits such as brand and corporate image promotion (Tukker & Tischner 2006a; Charter & Tischner 2001). Life cycle thinking of products or services has often been adopted to guide eco-design or sustainable product design and incorporate sustainability in decision making processes (Sundin 2009; Ramani et al. 2010).

With the resources, technologies and the global reach, corporations have a huge influence on the global economy and the motivation for sustainable development (Hart 1997). Sustainability should be perceived as opportunities for greater value creation rather than problems to be solved. As Hart (1997) stated:

> “Whereas yesterday’s businesses were often oblivious to their negative impact on the environment and today’s responsible businesses strive for zero impact, tomorrow’s businesses must learn to make a positive impact”.

2.2.3 Sustainability and electric vehicle batteries

Battery electric vehicles (BEVs) hold great promise to reduce environmental impacts and contribute to the sustainability of the transport sector (IEA 2013; Günther et al. 2015; Chan 2007). As the major component of an EV, batteries replace the fuel tank of conventional gasoline cars, which is the key to achieve the zero-emission goal of EVs. However, the zero-tailpipe-emission of EVs does not mean those battery-powered cars are clean and sustainable. Studies on the life cycle of EV batteries indicate that different stages of the battery life cycle have large potential environmental impacts: a) mining and production of materials, as well as energy and pollution of manufacturing processes during battery production; b) the coal-dominated electricity mix used to charge the batteries during the use phase; and c) pollution and energy consumption during EOL processing of the batteries (Zackrisson et al. 2010; Dunn et al. 2012; Ahmadi, Yip, et al. 2014).

The use of ever more exhausted materials, the environmentally questionable extraction and production processes have generated concerns about the material loss, energy consumption and pollution related to battery production (Larcher & Tarascon 2015; Gaines et al. 2011). Several hundred thousand tons of batteries are sold annually and if the batteries are not properly handled at their EOL, it is not just the battery, but all the energy and materials used to make the battery that are wasted. Discussions on the impact of battery recycling on the production life cycle burdens indicate that the recycling of battery materials can potentially reduce energy consumption of the batteries significantly (Gaines et al. 2011; Dunn et al. 2012).

End-of-life EV batteries will become a future waste management challenge, with projected annual waste flows reaching as high as 340,000 metric tons by 2040 (Richa et al. 2014). In general, lithium-ion batteries widely used for EVs are not considered to be hazardous to the environment due to the absence of toxic lead, mercury or cadmium (Larcher & Tarascon 2015). However, they may introduce potential environmental risks due to, for example, leakage of organic electrolytes, presence of heavy metal like nickel or cobalt and reactive lithium (Richa et al. 2014). On the other hand, it is estimated that the accumulative capacity from end-of-life EV batteries could reach 1000GWh globally by 2030, which would be enough to power the whole UK for 24 hours (Reid & Julve 2016). Those still capable batteries are likely to be chemically reprocessed and recycled or disposed unless we can do something else with them. And that would be a disaster, given the potential chemical waste and energy consumption related with recycling, as well as the huge capacity left in those batteries that would otherwise be valuable in further applications such as stationary energy storage (Elkind 2014).

Battery energy storage could bring substantial benefits to the power grid, enabling more dynamic operation of the power system (Luo et al. 2015). The power grid is facing great challenges with the increasing energy demand as well as the integration of intermittent renewable sources such as solar and wind power. The penetration of EVs also poses a challenge for the grid due to EV battery charging. Qian et al. (2011) modelled the load demand in a typical UK distribution system as a result of EV charging and showed that a 10% level of EV penetration would lead to an increase in daily peak demand by up to 17.9% while a 20% EV penetration would result in up to 35.8% increase in peak load under an uncontrolled charging scenario. Battery energy storage has been recognised as a promising approach to load balancing both at the supply and demand sides such as peak shifting and frequency regulation to help facilitate more efficient operation of the power system, thereby deferring or avoiding the grid infrastructure upgrade (Williams et al. 2012; Srivastava et al. 2012; Luo et al. 2015). Williams et al. (2012) showed in their study that battery storage equipped with smart control methods could add value to PV generated electricity: a 5kWh Lithium-ion battery system could drive the PV self-consumption level to 50% with a reduction to 55% of the peak injection into the grid.

Second-life batteries, although somewhat degraded, could still provide value in various energy storage applications (Ahmadi et al. 2015; Ambrose et al. 2014; Bräuer et al. 2016). B2U thus provides a potential way to increase the sustainability of EVs not only from the resource and energy aspects, but also in terms of the greener electricity that powers the EVs.

2.2.4 Circular economy

B2U is a specific example of the notion of a circular economy which has attracted increased attention in recent years from policymakers as well as businesses (European Commission 2015; Wu et al. 2014; Stahel 2013; Su et al. 2013; Yong 2007; Feng & Yan 2007; Lacy & Rutqvist 2015). The circular economy concept traces back to and has been refined by different schools of thought such as industrial ecology (Graedel & Allenby 1995), natural capitalism (Hawken et al. 1999), cradle-to-cradle design (McDonough & Braungart 2002), performance economy (Stahel 2006), and more recently, the blue economy (Pauli 2010).

In 1989, Robert Frosch originated the concept of the human cycling of resources as a system challenge and published what is regarded by many as the first paper of industrial ecology: "Strategies for manufacturing" (Frosch & Gallopoulos 1989). In this paper, Frosch & Gallopoulos (1989) emphasized the importance of transforming traditional industrial activities into a more integrated model: an industrial ecosystem, where material and energy consumption are optimised with the waste generation minimised. After the paper was published, the industrial ecology concept was adopted by many corporations to reflect their ways of resource and waste management.

Industrial ecology is defined by Graedel & Allenby (1995) as "means by which humanity can deliberately and rationally approach and maintain sustainability, given continued economic, cultural, and technological evolution… It is a system view in which one seeks to optimize the total materials cycle from virgin material, to finished material, to component, to product, to obsolete product, and to ultimate disposal". It focuses on the connections between stakeholders within the industrial ecosystem to create closed-loop systems that perform as close to the biological ecosystem as possible. Various tools and methodologies of industrial ecology have been developed including life cycle assessment (LCA), design for environment, material flow analysis and input-output analysis to help both industries and governments to evaluate and improve environmental as well as operational performance (Graedel & Lifset 2015). Given its multi-disciplinary nature, its focuses on resource and waste flows and its widely applicable tools and principles, industrial ecology is uniquely positioned to the systematic investigation of circular economy and has the potential to truly become "the science of the circular economy" with the integration of social theories from other multiple disciplines such as law, economics, system dynamics, sociology and organizational studies (Blomsma & Brennan 2017).

In contrast to today's linear economy (take, make, dispose), a circular economy is a regenerative economic model (Figure 2.4) in which resource input, emissions, waste and energy leakage are minimised by slowing, narrowing and closing the material and energy loops (Ellen MacArthur Foundation 2015). A circular economy aims to keep resources in productive use for as long as possible, extract the maximum value from them whilst in use, then recover and regenerate products and/or raw materials at the end of their service life (Ghisellini et al. 2016; Lieder & Rashid 2016; Ellen MacArthur Foundation 2012). By closing the loop of material flows throughout the product life cycle and using the raw materials and energy through multiple phases, the circular approach seeks to ultimately decouple economic growth from constrained natural resources (Ellen MacArthur Foundation 2012).

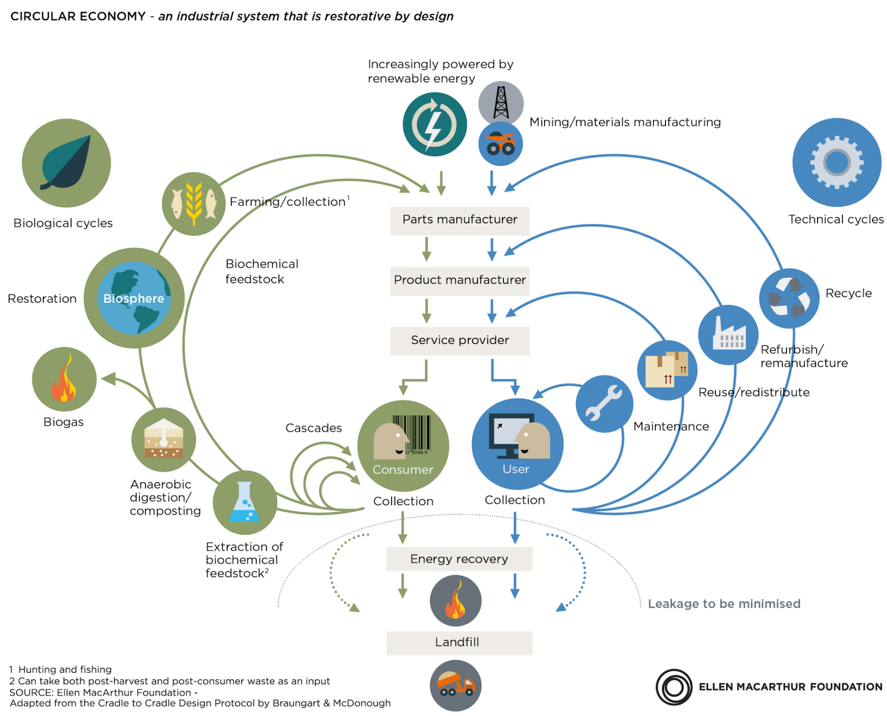

Figure 2.4 Outline of a circular economy (Ellen MacArthur Foundation 2015)

As discussed in the previous section, life cycle thinking considers the environmental, social and economic impacts of a product over its entire life cycle. Influenced by the ideas of life cycle thinking, circular economy represents a resource-based view of a means to deliver improved sustainability (Wu et al. 2014; Geissdoerfer et al. 2017). The 3Rs principle – well known as reduce, reuse, and recycle – is commonly discussed in the circular economy literature and is considered to be a good principle for guiding the implementation of circular economy in practice (Yong 2007; Feng & Yan 2007; Hideto et al. 2011; Su et al. 2013).

Reduction in the input of resources and energy as well as in the output of waste is aimed at improving efficiency in production and consumption processes whistle also reducing the environmental impacts (Hideto et al. 2011). Reuse aims to make full use of used products or components with any remaining usage function for the same purposes (EU 2008). Compared with the manufacturing of new products from raw materials, reuse could deliver substantial environmental benefits since it requires less resource, energy, and labour and avoids many potential environmental risks such as toxic emissions (Castellani et al. 2015; Ghisellini et al. 2016). Recycling translates wastes into new resources and offers the opportunity for manufacturing firms to benefit from still usable waste materials. It also reduces the quantity of waste that need to be disposed of and thus contributes to reduced environmental burdens (Yong 2007).

Under the 3Rs principle, various product-life extension actions including build-to-last design, repair, refurbishing, remanufacturing, repurposing, reuse, and recycling have been widely discussed and adopted in practice (Lacy & Rutqvist 2015; Stahel 2013; Jawahir & Bradley 2016). Although the recycling principle acts as a critical connection bridging the production and consumption phases, it should be underlined that recycling might be the least sustainable solution compared with other life extension activities (e.g. reuse, repair and remanufacturing) in terms of resource efficiency, environmental impacts and profitability (Stahel 2013; Ghisellini et al. 2016). Circular systems use inner loops whenever possible, for example, reuse and recovery, rather than recycling, thereby preserving more embedded energy, materials and other value and keeping the technical components and materials circulating

(Ellen MacArthur Foundation 2012). By extending the product life, these circular systems maximise the number of product life cycles and/or optimise the time spent in each cycle wherein recycling should be the last step (Castellani et al. 2015).

As discussed in the previous section, the EOL issues present a future waste management challenge for EV batteries. With the market penetration of EVs increasing rapidly each year, EOL solutions including remanufacturing, repurposing and recycling of EV batteries have been discussed in the literature (Foster et al. 2014a; Ramoni & Zhang 2013; Standridge & Corneal 2014). Since those batteries could still hold substantial value at the end of their vehicle life (Neubauer et al. 2015), effective and efficient EOL solutions that maximise the residual value of the batteries while minimising their environmental impacts are crucial. The concept of circular economy provides insights into improved sustainability of EV batteries through designing multiple life cycles for the batteries to recover the materials and energy embedded in the batteries.

Some papers show that although recycling will eventually be necessary for all batteries, there are many issues that make recycling in isolation less justifiable. Remanufacturing the batteries for return to vehicle application or repurposing them for non-vehicular, stationary energy storage are recognised as better options before recycling (Ramoni & Zhang 2013; Foster et al. 2014b). The feasibilities of remanufacturing and repurposing have been investigated and both depend on many variables such as remanufacturing/repurposing cost, battery quality and new battery price (Neubauer et al. 2015; Foster et al. 2014a). As still capable energy storage devices, some authors argue that batteries retired from EVs could be applied in less-demanding, non-vehicular applications (Cready et al. 2003; Williams 2012; Faria et al. 2014; Ambrose et al. 2014). Remanufacturing is considered to be the most desirable EOL scenario but is the most stringent in terms of battery quality (DeRousseau et al. 2017). And while remanufacturing is widely discussed in the literature, many automotive companies have already launched initiatives and businesses to repurpose a second-life for those batteries in various energy storage applications (Gohla-Neudecker et al. 2015).

2.3 Business models

This section presents the literature review in the field of BMs. An overview of the BM research in the current literature is firstly presented. Literature in BM innovation, BMs for sustainability and product-service systems is then discussed respectively. As shown in Figure 2.5, this section presents key papers in the BM research as well as the intersection of BMs and sustainability (green shadow), but excludes the intersections with B2U. The literature in the intersections with B2U will be discussed later.

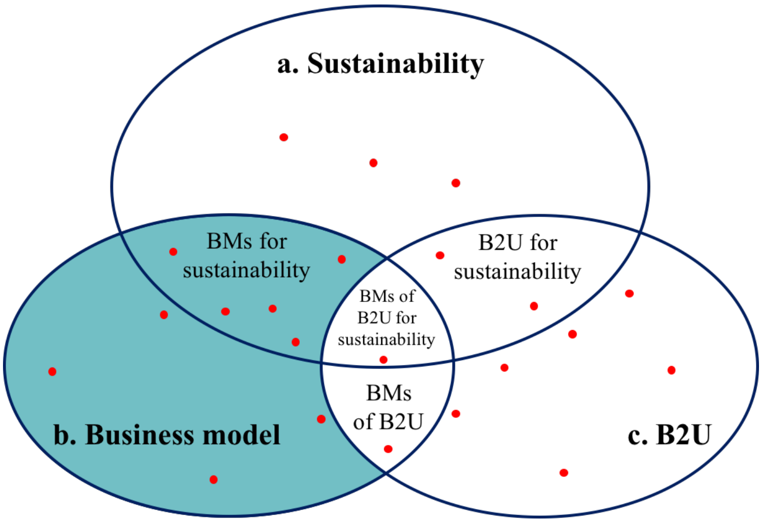

Figure 2.5 Literature review in the field of BMs

2.3.1 An overview of business model research

The term 'business model' first appeared in the 1950s but rose to prominence only towards the end of the 1990s with the advent of the Internet boom (Osterwalder et al. 2005; Casadesus-Masanell & Ricart 2010). Since then, BMs have been studied in an explosive number of peer-reviewed academic publications as well as popular business press. Over the past two decades, researchers have been investigating BMs across a wide range of fields including technology and innovation (Chesbrough & Rosenbloom 2002; Chesbrough 2007; Baden-Fuller & Haefliger 2013), business strategy (Yip 2004; Casadesus-Masanell & Ricart 2010; Teece 2010) and sustainability (Schaltegger et al. 2012; Boons & Lüdeke-Freund 2013; Short et al. 2013; Schaltegger et al. 2016; Bolton & Hannon 2016).

Despite extensive and intensive research on this subject, there seems to be a lack of consensus towards a widely accepted language that can be used by researchers and practitioners to describe BMs from different perspectives (Magretta 2002; Zott et al. 2011; Massa et al. 2017). At a general level, BMs are broadly defined as the logic of how a company does business, creates and delivers value to customers, and earns a profit from delivering that value (Magretta 2002; Teece 2010). Every business enterprise operates under a certain BM, explicitly or implicitly, that explains the value creation, value delivery and value capture mechanisms of its business (Casadesus-Masanell & Ricart 2010; Teece 2010; Richardson 2008).

The pervasiveness and extensive use of the term business model suggest the significance of the concept, but the lack of consistent definitions and construct boundaries have caused some criticisms of the term (Porter 2001; DaSilva & Trkman 2014; Massa et al. 2017). It has been frequently confused with other popular business terms such as strategy (DaSilva & Trkman 2014). To clarify and defend the BM as a distinct concept, some studies investigated the differences and relationships between the BM and strategy (Yip 2004; Spieth et al. 2016; DaSilva & Trkman 2014; Teece 2010; Casadesus-Masanell & Ricart 2010). In general, despite some overlaps between the two concepts, the BM is considered to be more generic than a business strategy and tackles some issues overlooked by the traditional strategy literature (Massa et al. 2017). For example, the BM emphasises value creation in the first place and is constructed around creating and delivering the value to customers or all the firm's exchange stakeholders, thereby capturing benefits for the company itself (Zott & Amit 2010). Strategy, on the other hand, has stronger focus on value capture and sustaining the firm, and is more inclined towards shareholder value rather than the creation of value for the business and its stakeholders (Chesbrough & Rosenbloom 2002).

To understand why some BMs outperform others, researchers have moved on from the definitions and taxonomies to study the elements, frameworks as well as applications and conceptual tools of BMs (Osterwalder & Pigneur 2010; Johnson et al. 2008; Al-Debei & Avison 2010; Morris et al. 2005). These studies are interrelated and complementary, and provide more comprehensive insights into this important concept. Building upon central ideas and theories in business strategy, Morris et al. (2005) introduced an integrative framework to characterize BMs. The framework comprises six elements: offering, market, internal capability, competitive strategy, economic and personal/investor factors. Osterwalder & Pigneur (2010) proposed a BM canvas that has been widely adopted in strategic management and lean start-ups. The BM canvas comprises nine building blocks: value propositions, customer segments, customer relationships, channels, key partners, key activities, key resources, cost structure and revenue streams. Johnson et al. (2008) described BMs as consisting of four interlocking elements: customer value proposition, profit formula, key resources and key processes. Richardson (2008) proposed a widely accepted BM framework around the concept of value which consists of three elements: value proposition, value creation and delivery, and value capture.

Although oriented towards different purposes in the context of different domains, those frameworks converge in some key themes, for example, the existence of value proposition, value chain configuration/value network, value creation, and the revenue models. Moreover, the BM is emerging and being acknowledged as a new unit of analysis (Zott et al. 2011).

One criticism of much of the literature is that BM has been regarded as a property of the firm and the BM literature is largely examining BMs at the firm level, which fails to consider the influence of the business network (Mason & Spring 2011). Some researchers pointed out the importance of extending the focus of analysis beyond the entity of the firm to include the interactions between stakeholders and their relationships. For example, Bankvall et al. (2017) claimed that the firm-centric perspective of BM is problematic wherein it is impossible for individual firms to govern all relevant resources and activities. Taking a network perspective, Palo and Tähtinen (2013) examined network-embedded BMs where "a net of companies will create customer and network value by developing collective understanding of the business opportunities and shaping the actions to exploit them". Mason and Spring (2011) claimed that the firm-centric perspective has restricted the "flexibility and creative ambiguity" of the BM notion. They suggested "a more open mind about the BM concept and the relevant level of analysis – firm, network, industry or market”. These studies exemplify an emerging view that BMs need to be developed beyond the firm-centric perspective.

The activity system perspective of BMs is proposed by some researchers to encourage systemic, holistic thinking on BMs (Afuah & Tucci 2001; Zott & Amit 2010; Zott & Amit 2007). Zott and Amit (2010) conceptualized a firm’s BM as an activity system “of interdependent activities that transcends the focal firm and spans its boundaries”. The activity system view emphasises the interdependencies among activities and stakeholders and is “geared toward total value creation for all parties involved”. The activity system perspective of BMs extends beyond the company focus (Zott & Amit 2010) and allows a wider set of stakeholders to be included, necessitating a broader system-level perspective of value creating logic.

In summary, BM has been widely used as business jargon for a long time but it is often misused and its meaning poorly understood. In the academic world, the BM is still an emerging research topic and is not yet mature. The studies are mostly based on the authors’ perception of the concept or the analysis of some classic business examples, but rarely on empirical studies. The significance and pervasiveness yet lack of unifying language of the BM concept demonstrate the need for more in-depth studies on BMs based on empirical cases.

In this study, BM is examined from the value perspective and is defined as the logic of value exchange within the network of stakeholders. The dominant views adopted for this research are Zott and Amit's (2010) activity system perspective of BMs that transcends the focal firm and spans its boundaries, as well as Richardson's (2008) framework consisting of the three BM components – value proposition, value creation and delivery, and value capture. The construction of a BM analytical framework based on the literature will be explained in detail in Chapter 3.

2.3.2 Business model innovation

In times of instability and complexity, the importance of innovation on the competitiveness of a company is well recognized (Calia et al. 2007). According to IBM's global survey among CEOs (IBM 2010), over 70 per cent shared the view that "complexity is only expected to change" and that "incremental changes are no longer sufficient in a world that is operating in fundamentally different ways". For a long time companies have invested substantially on technology, product and process innovations, from research and development to specialized resources and sourcing approaches, in order to keep competitive advantages and achieve economic growth (Amit & Zott 2012).

However, most companies now find it increasingly difficult to differentiate on technologies, products or services alone (IBM 2006). With the growing cost of technology and product development and the shortening life cycle of new products, along with the uncertainty of the innovation returns, companies have been increasingly reluctant to bet on technology and product innovations (Amit & Zott 2012; Chesbrough 2007). Rather, both new entrants and incumbent firms are now turning towards BM innovation as complementary, if not alternative to technology, product and process innovations (Lindgardt et al. 2009; Amit & Zott 2012). Unlike single function strategies such as product improvement or sales model enhancement, BM innovation is more systemic (Velu & Stiles 2013) and often more difficult for competitors to imitate or replicate (Casadesus-Masanell & Ricart 2007; Casadesus-Masanell & Ricart 2010; Amit & Zott 2012). If a BM proves to be sufficiently differentiable and thus hard to imitate, BM innovation itself becomes a source of competitive advantage of a company (Chesbrough 2007; Teece 2010; Chesbrough 2010).

Researchers have been investigating what constitutes BM innovation and how to successfully innovate BMs (Amit & Zott 2012; Chesbrough 2010; Chesbrough 2007; Giesen et al. 2007; Lindgardt et al. 2009; Wang et al. 2009). As with BMs, there is no consensus yet on the definition of BM innovation. In general, most authors agreed that BM innovation is about searching for new logics of the firm, changing the way of doing business and adopting different modes of value proposition, value creation and value capture (Teece 2010; Amit & Zott 2012; Casadesus-Masanell & Zhu 2013). BM innovation does not necessarily involve new technologies, product and service offerings, or new market segments (Markides 2006). The well-known BM innovation examples such as Dell's built-to-order system, Toyota's production system and Zara's supply chain for fast fashion did not introduce any new technologies. Rather, they disrupted traditional innovation approaches through new ways of delivering existing products or services based on existing technologies to existing market (Girotra & Netessine 2011). However, it does not mean that BM innovation is independent of other innovations; more often, they are complementary and influence each other (Amit & Zott 2012). BM innovation is sometimes enabled by technological innovations such as information technology which greatly influences the way in which a BM can be created and innovated (Baden-Fuller & Haefliger 2013).

BM innovation is frequently linked to firm performance and regarded as a key success driver for many companies (IBM Global Business Services 2006). To understand how BM innovation could yield the best results, Giesen et al. (2007) developed a framework consisting of three main types of BM innovation which can be used alone or in combination: a) industry models: innovating the industry value chain; b) revenue models: innovating offerings and revenue models; and c) enterprise models: innovating the structure of the enterprise and the role it plays in new or existing value chains.

BM innovation is much more challenging than product or technology innovations in that it poses some risks and uncertainties by pushing people beyond the comfort zone – changing the way of doing business that they are familiar with (Chesbrough 2010). According to Clayton and Michael (2003), BM innovation may conflict with the existing BMs or the asset configurations that support the current BMs. However, Chesbrough (2010) indicated that the barriers to BM innovation lie in the 'dominant logic' of a firm which might make them blind to potentially valuable new opportunities failing to fit the prevailing BMs. In either case, as summarized by Chesbrough (2010), the lack of commitment to experiment as well as a systematic, potent tool for BM innovation could keep companies away from numerous potential profits. Taking a dynamic perspective of the evolution of BM innovation, Sosna and colleagues (2010) echoed this view by emphasizing the importance of trial-and-error learning for BM innovation.

To keep competitive advantages, many authors suggest that companies need to innovate their BMs intelligently, along with technology, product and process innovations (Chesbrough 2010; Amit & Zott 2012). In the context of growing labour division in the market, a new system of innovation which is an increasingly open process enables firms to become more effective in creating, delivering and capturing value (Chesbrough 2007). Moreover, researchers and practitioners are increasingly interested in how BM innovation could contribute to the sustainability management of companies (Schaltegger et al. 2016). Some authors claimed that "the need to advance the business model innovation study is particularly evident when it comes to sustainability" (Girotra & Netessine 2013).

2.3.3 Business models for sustainability

There is a growing awareness among researchers and practitioners that the sustainability of organizations is an integral part of sustainable development at the societal level (Schaltegger et al. 2016; Salzmann et al. 2005). However, it is already apparent that the prevailing BMs might be inadequate to meeting the challenges of sustainability (Wells 2013). Scholars and practitioners are therefore exploring new BMs that move beyond the dominant neoclassic economic model to not only maintain or increase economic prosperity, but also achieve environmental and social goals (Stubbs & Cocklin 2008; Schaltegger et al. 2016).

BM offers a potential approach to overcoming internal and external barriers to sustainability innovation and integration (Boons & Lüdeke-Freund 2013). As a holistic concept, BM provides a platform to support systematic, on-going creation of business cases for sustainability (Schaltegger et al. 2012; Salzmann et al. 2005). Schaltegger et al. (2012) defined business cases for sustainability as ones that involve repurposing the business logic to incorporate voluntary societal or environmental activities and achieve economic success thereof. Rather than ad-hoc, event-driven business cases for sustainability, innovations that integrate social and environmental dimensions should be introduced into the core of the business logic to change the way companies operate to achieve greater sustainability (Bocken et al. 2014; Stubbs & Cocklin 2008; Bocken et al. 2013). In this case, BMs for sustainability provide a potential means to link non-monetary social and environmental activities with economic profits through the on-going creation of business cases for sustainability in a systematic manner (Schaltegger et al. 2012).

Stubbs and Cocklin (2008) conceptualized sustainable BMs, which embed sustainability into business purposes and processes to shape the driving force of the firm and guide decision-making. A sustainable BM treats nature as an important stakeholder and aims to create value for all stakeholders, which would also include society. Sustainable BMs take a TBL approach and require a systemic consideration of stakeholder interests and responsibilities for mutual value creation (Evans et al. 2017; Bocken et al. 2014). Unlike traditional BMs which focus on shareholder and customer value, multi-stakeholder engagement and collaboration are regarded as a necessary condition for building sustainable BMs, where stakeholders collaboratively develop sustainability solutions for the whole system that create on-going benefits for all the parties involved (Hart & Milstein 2003; Stubbs & Cocklin 2008).

Bocken et al. (2014) formalised BM innovation categorizations to describe widely discussed but fragmented mechanisms and solutions that might contribute to a unifying analysis of BMs for sustainability. In this paper, BM innovation for sustainability is defined as "innovations that create significant positive and/or significantly reduced negative impacts for the environment and /or society, through changes in the way the organization and its value-network create, deliver value and capture value or change their value proposition". Eight sustainable BM archetypes were identified from the literature under three main types of BM groupings: technological, social and organizational oriented innovations (Figure 2.6). Other researches aiming to categorize BMs for sustainability include Boons and Lüdeke-Freund (2013), who proposed a classification of BMs for sustainability as social, technical and organizational BMs.

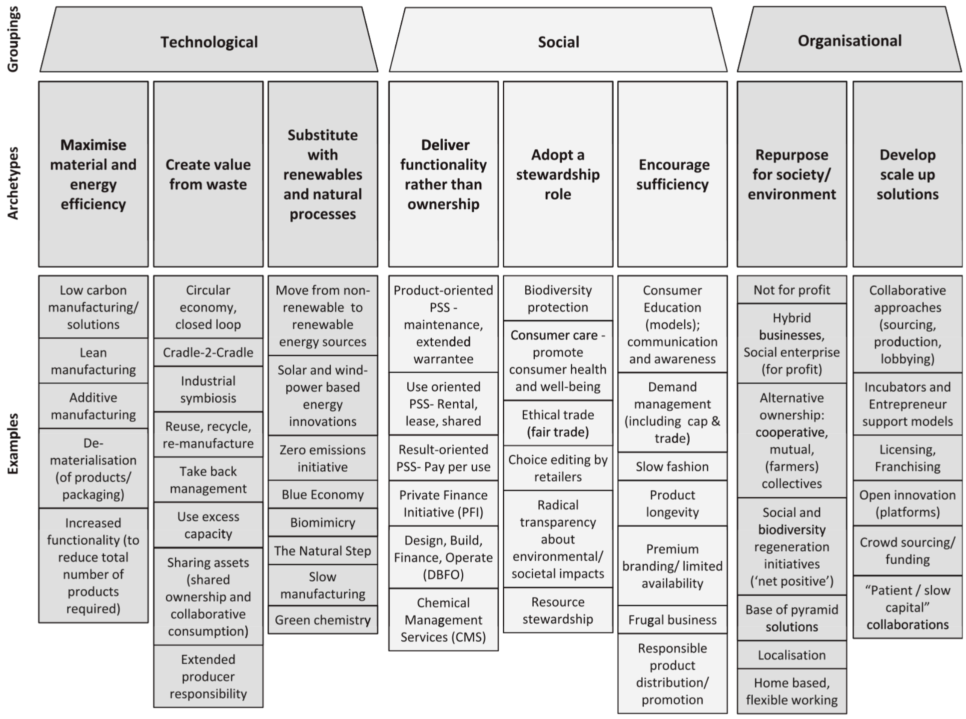

Figure 2.6 The sustainable business model archetypes (*Source: Bocken et al. 2014)*

Based on the previous work of various researchers, Schaltegger et al. (2016) proposed the following definition of a BM for sustainability:

> "A business model for sustainability helps describing, analyzing, managing, and communicating (i) a company's sustainable value proposition to its customers, and all other stakeholders, (ii) how it creates and delivers this value, (iii) and how it captures economic value while maintaining or regenerating natural, social, and economic capital beyond its organizational boundaries."

Apart from conceptualizing BMs for sustainability, frameworks have been developed to facilitate the integration of sustainability into BMs. Schaltegger et al. (2012) proposed an integrated framework including sustainability strategy, business case drivers and BM innovation as a means to strategically create business cases for sustainability on a continuous basis. This framework links BM innovation of different degrees with three types of sustainability strategies:

- Defensive strategies: require moderate BM changes, e.g. BM adjustment or adoption to protect current BMs, focusing mainly on risk and cost reduction.
- Accommodative strategies: experiment with current model to achieve BM improvement with basic changes in sustainability issues like renewing production processes and changing network partners.
- Proactive strategies: lead to radical changes to the core business logic and BM redesign, unfolding the full potential for sustainability.

These strategies with different intensities on change for sustainability result in different levels of BM innovation, with accommodative and proactive being the most promising and impactful.

There are many business examples with sustainable potentials within their BMs, for example, the Better Place's battery switching model that separates car ownership from battery ownership to make the car battery a changeable item (Boons & Lüdeke-Freund 2013; Kley et al. 2011). In this radical BM, customers do not pay for the battery, but pay for the mobility service provided in the form of kilometers driven. Although bankrupted in 2013, Better Place aimed to reduce initial investment for customers and solve the range anxiety issues related to EVs. The innovative BM of the car manufacturer retaining battery ownership also enables better management of the battery over its life cycle, which encourages a more sustainable use of the battery.

A sustainable BM is multidimensional and complex, thus few known successful examples exist (Hart & Milstein 2003). The creation of or transformation to a sustainable BM faces multifold challenges. Evans et al. (2017) summarised the main challenges for the creation of sustainable BMs found in the literature (Table 2.1).

Table 2.1 Challenges for the creation of sustainable BMs (Evans et al. 2017)

Challenges	Authors
Triple bottom line The co-creation of profits, social and environmental benefits and the balance among them are challenging for moving towards SBMs.	Hart and Milstein, 2003; Stubbs and Cocklin, 2008; Schaltegger *et al.*, 2012
Mind-set The business rules, guidelines, behavioural norms and performance metrics prevail in the mind-set of firms and inhibit the introduction of new business models.	Johnson *et al.*, 2008; Yu and Hang, 2010; Boons and Lüdeke-Freund, 2013
Resources Reluctance to allocate resources to business model innovation and reconfigure resources and processes for new business models.	Chesbrough, 2010; Zott *et al.*, 2011; Björkdahl and Holmén, 2013
Technology innovation Integrating technology innovation, e.g. clean technology, with business model innovation is multidimensional and complex.	Hart and Milstein, 2003; Yu and Hang, 2010; Zott *et al.*, 2011
External relationships Engaging in extensive interaction with external stakeholders and business environment requires extra efforts.	Stubbs and Cocklin, 2008; Vladimirova, 2012; Boons and Lüdeke-Freund, 2013
Business modelling methods and tools Existing business modelling methods and tools, e.g. Osterwalder and Pigneur (2010) and Johnson *et al.* (2008), are few and rarely sustainability driven.	Björkdahl and Holmén, 2013; Girotra and Netessine, 2013; Yang *et al.*, 2014

These challenges suggest that creating BMs for sustainability is a major business transformation and therefore might be risky. Vladimirova (2012) identified key competences to reduce these risks, for example, to be aware of their current BMs and sustainability vision, to understand their business environment and requirements for change, and to countervail pressures for the change. In general, the field of BMs for sustainability is still under-researched and there is a lack of empirical studies that provide practical insights for companies to transform or innovate BMs for sustainability (Wells 2013; Schaltegger et al. 2012). In this thesis, BMs for sustainability is taken as having a multi-stakeholder, systemic perspective rather than firm-centric.

The importance of switching from the current linear model of economy to a circular economy in moving towards sustainability has been discussed in Section 2.2.4. The move towards a circular economy is an example of a radical change, which will require not only new material and production design, as well as global reverse networks, but also new business models (Lewandowski 2016; Bocken et al. 2016). Companies need to innovate towards circular business models (CBMs) to grasp the opportunities of a circular economy.

A CBM is defined by Linder & Williander (2017) as “a business model in which the conceptual logic for value creation is based on utilizing economic value retained in products after use in the production of new offerings”. In contrast to a linear business model, a CBM enables companies to create and capture value through slowing and closing resource loops (Bocken et al. 2016). CBMs thus overlap with reverse supply chains and always involve lifespan extension or product recovery activities such as remanufacturing, reuse and recycling. CBMs often contain offerings where the owernship of a product is retained, for example, product service systems (PSS) which facilitates the return flow of products from users to producers. Many of the strategic issues associated with moving towards CBMs have primarily been discussed in PSS literature (Linder & Williander 2017). PSS will be discussed in detail in the next section.

2.3.4 Product-service systems

A product-service system (PSS) is in general defined as an integrated combination of products and services to fulfil specific customer needs and generate greater value (Mont 2002; Tukker 2004; Baines et al. 2007). Many see PSS business models as an excellent means to enhance corporate competitiveness and move society towards sustainability due to its significant potential to synergise economic, social and environmental benefits (Maxwell & Vorst 2003; Tukker & Tischner 2006b). A PSS business model emphasises the ‘sale of use/functionality’ through integrated services rather than just the ‘sale of product’, which restructures the customer relationships, risks, liabilities and costs associated with traditional product ownership (Baines et al. 2007; Tukker 2015).

A well-known example of PSS is the Total-Care Package offered to airlines by Rolls-Royce, which delivers the “power-by-the-hour” rather than selling gas turbine engines (Neely 2007; Boehm & Thomas 2013). Instead of transferring the ownership of the engines, this new model enables Rolls-Royce to have direct access to the asset and data, thereby improving asset utilization and performance, as well as reducing total cost and the environmental impact (Baines et al. 2007).

In general, PSS is classified into three categories based on the degree of service involved: product-, use- and result-oriented PSS (Tukker 2004).

- Product-oriented PSS focuses on selling products that are accompanied by some extra services such as maintenance, repairing, advice on use and consultancy.
- Use-oriented PSS is when the provider keeps ownership of the product and makes the product available in a different form such as leasing, renting, sharing and pooling.
- Result-oriented PSS is when the provider and customer agree on a result and the provider sells the agreed result without any pre-determined product forms (e.g. selling the copying service rather than the photocopier).

Based on the three main PSS types, Tukker (2004) proposed eight archetypical PSS models (Figure 2.7). The market and sustainability potential of the eight PSS models were evaluated and situations where there are reinforcing business and sustainability incentives analysed. It was found that some subtypes under the use- and result-oriented PSS are more promising in sustainability terms, for example, renting, sharing, pooling and functional PSSs (type 4, 5, 8 shown in Figure 2.7).

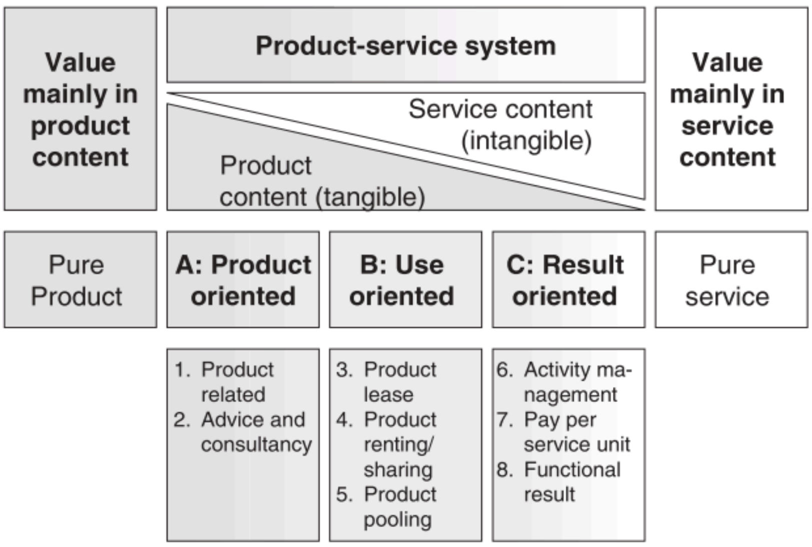

Figure 2.7 Main and the eight subcategories of PSS (Tukker 2004)

The relationship between products and services in PSS models has been examined in many studies (Geum & Park 2011; Mathieu 2001). Cusumano et al. (2015) proposed three types of services that product firms might offer: *smoothing* and *adapting* services which complement products, and *substitution* services which completely replace the purchase of a product. The different kinds of services vis-à-vis industry evolution were analysed. The authors of the paper proposed that services are not only important when the industry is mature but also during the ferment phase of an industry, which could help ignite a new market.

Many authors have claimed that PSS offer potential sustainable benefits, for example, increased resource efficiency (Tukker 2015), stronger customer relationship (Baines et al. 2007), differentiated offering and increased revenues (Cavalieri & Pezzotta 2012; Mathieu 2001). However, the development of sustainable PSS is still at an early stage. More in-depth research is needed on how to embed sustainability into the PSS design and how to capture the sustainable benefits offered by PSS.

In summary, the fields of BMs in general, BM innovation, BMs for sustainability and PSS are still under-researched, although interests are growing. There is no conceptual consistency or consensus on the definition, characterization and boundaries of these concepts, which results in the confusion and diversified perspectives in the BM research. The significance yet lack of unifying language of the BM related concepts suggests the need for more in-depth studies based on empirical cases.

2.4 Battery second use

The literature search on the research context B2U started with the EV batteries as the object of interest and areas focusing on the second use of the batteries. However, B2U is poorly defined in both the literature and practice, and several synonyms were identified during the searching processes. Therefore, the keywords used for searching the B2U literature are: ((“electric vehicle batteries” OR “used batteries” OR “end-of-life batteries”) AND (“second use” OR “repurposing” OR “re-use” OR “second life”)).

This section presents the literature review in the field of B2U, including the intersections with sustainability and BMs as shown in Figure 2.8 (green shadow). An overview of the history of B2U studies is firstly presented. The landscape of existing B2U studies and the main findings in those different fields are then mapped, followed by a comment and discussion on the status of the B2U research in the literature.

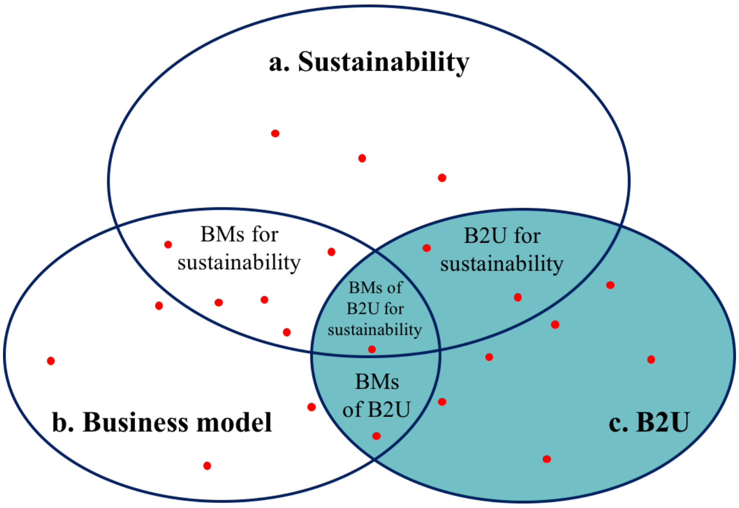

Figure 2.8 Literature review in the field of B2U

2.4.1 An overview of the history of B2U studies

The idea of B2U or battery repurposing is not new to the industry. Both the benefits and concerns of B2U have been widely discussed in various newspaper articles, industrial reports and academic papers (Neubauer et al. 2012; Faria et al. 2014; Heymans et al. 2014). In recent years, with the rapid development of EVs, governments are increasingly concerned about the EOL issues of EV batteries. Some countries have started to incorporate B2U into their policy development for EVs. The Office for Low Emission Vehicles (OLEV) in the UK, for example, stated in the "Strategy for ultra-low emission vehicles in the UK" published in 2013:

> "The Government will continue to support developments in the second-life use of batteries, which maximise their value and alleviate concerns about disposal…Over time we expect to

see a viable battery reuse and recycling industry develop in the UK as volumes increase" (OLEV 2013).

Investigations into the further utilisation of retired EV batteries in a secondary application were mostly motivated by the potential profits generated to reduce the capital cost of EVs (Williams & Lipman 2010; Williams & Lipman 2010; Neubauer & Pesaran 2011). Currently, the battery constitutes the single most expensive part of an EV. For example, the battery pack alone for the recently launched Chevy Volt (around $40,000) is estimated to cost up to $15,000 (Williams & Lipman 2010). Through extending the lifetime and recapturing the residual value of the batteries in second-use applications, B2U may help bring down either the battery cost for EV manufacturers or the total cost of ownership (TCO) for EV customers (Neubauer et al. 2015).

Studies on B2U started in the late 1990s, which focused on nickel metal hydride (NiMH) batteries as they were the most promising EV battery technology at that time (EPRI 2000). The first published study was Argonne National Laboratory's "Electric vehicle battery 2nd use study" conducted for the United States Advanced Battery Consortium (USABC) (Argonne National Laboratory 1998). This study demonstrated the competitive or even superior performance of used automotive NiMH batteries compared to new lead-acid batteries in several secondary applications. Although limited in the number of cases, the demonstrated competence of second-life batteries motivated further research into B2U.

After that, a study by Cready et al. (2003) investigated the technical and economic feasibility of applying used NiMH EV batteries in stationary applications and "did not come across any insurmountable technical barriers to the implementation of a second use scheme". This report also indicated several important issues to be addressed: the standardization of battery modules, the mechanism of applying B2U value to EV owners, the warranty terms and costs, and the perceived value of used batteries compared to new batteries in customers' minds. However, only a few studies on B2U existed at that time and there was no large-scale commercialisation of second-life batteries in practice due to the low EV penetration.

Rapid development of EVs since the last decade and advances in battery technology from NiMH to Li-ion reignited interests in B2U as a strategy for overcoming EV cost hurdles (Neubauer et al. 2015). This has motivated substantial published studies that investigate B2U from various perspectives. Since then, studies have been refined to include investigation of technical and economic feasibility of B2U in various stationary storage applications (Wolfs 2010; Narula et al. 2011; Beer et al. 2012; Lih et al. 2012; Neubauer et al. 2012; Warner 2013; Elkind 2014; Foster et al. 2014b; Heymans et al. 2014), of quantifying the effect of B2U on EV cost reductions (Williams & Lipman 2010; Neubauer & Pesaran 2011), of scenario analysis and optimisation (Viswanathan & Kintner-meyer 2011; Keeli & Sharma 2012), of environmental feasibility of extending the life of EV batteries (Ahmadi et al. 2014) and so on. The discussions on these studies are expanded and findings explained in detail in the next section.

A growing interest in the topic of B2U can be seen among researchers from various fields. It was found from the existing studies that B2U strategies are highly likely to be technically and economically viable under certain usage scenarios (Beer et al. 2012; Neubauer et al. 2012). However, the feasibility and profitability of B2U are still subject to uncertainties in, for example, battery degradation and regulatory structures (Elkind 2014) . Studies also show that although B2U is not likely to significantly affect today's EV prices, there could be enormous environmental and social benefits from second-life batteries which need further investigations (Neubauer et al. 2015).

2.4.2 Landscape of extant B2U studies

To date, researchers have been investigating B2U from various aspects through a diverse range of approaches. This section presents a landscape of extant B2U studies and maps the main findings in those different fields. In general, the extant B2U studies can be categorised into four groups: a) feasibility studies; b) trade-off analysis and optimisation; c) technical and operational analysis; d) market analysis and BMs. The challenges of B2U discussed in the extant B2U studies are also presented. The various aspects of B2U investigations under the four categories and the representative studies are summarised in Table 2.2.

Table 2.2 Summary of the four categories of extant B2U studies

Category	Aspects of B2U investigations
a) Feasibility studies	• Economic returns and effects on reducing EV price (Wolfs 2010; Narula et al. 2011; Beer et al. 2012; Williams & Lipman 2011; Neubauer & Pesaran 2011; Heymans et al. 2014; Canals Casals et al. 2014) • Energy and environmental benefits (Ahmadi et al. 2014; Ahmadi et al. 2015; Sathre et al. 2015) • Availability of second-life batteries and potential uses (Shokrzadeh & Bibeau 2012; Skarvelis-Kazakos et al. 2013; Neubauer et al. 2015)
b) Trade-off analysis and optimisation	• Trade-offs of key parameters and optimisation of battery usage over first and second life (Viswanathan & Kintner-meyer 2011; Lih et al. 2012; Bowler 2014)
c) Technical and operational analysis	• Technical aspects of B2U such as battery degradation, remaining battery lifetime and thermal and safety management systems (Lih et al. 2012; Neubauer et al. 2012; Ahmadi et al. 2014; Ambrose et al. 2014; Strickland et al. 2014) • Operational aspects of second-life battery systems such as control strategies, decision support systems and system design (Gohla-Neudecker et al. 2015; Monhof et al. 2015; Beverungen et al. 2016; Keeli & Sharma 2012)
d) Market analysis and business models	• Market form analysis of B2U (Klör et al. 2015) • Business model studies of B2U (Lih et al. 2012; Beer et al. 2012; Klör et al. 2015; Bräuer 2016; Bräuer et al. 2016)

a) Feasibility studies

The first category of studies focuses on analysing the economic and environmental feasibilities of repurposing second-life batteries for certain energy storage applications. Economic returns or potential revenues from B2U were estimated under specific usage scenarios and effects on reducing EV initial cost evaluated (Wolfs 2010; Narula et al. 2011; Beer et al. 2012; Williams & Lipman 2011; Neubauer & Pesaran 2011; Heymans et al. 2014; Canals Casals et al. 2014). These studies show that B2U is economically viable but the ability to reduce upfront cost of EVs is uncertain. For example, Neubauer & Pesaran (2011) estimated the ability of B2U to reduce the initial battery cost by up to 11%.

The energy and environmental benefits of B2U in energy storage were also studied by some researchers in terms of the reduction in life cycle environmental impacts of both EVs and power systems (Ahmadi et al. 2014; Ahmadi et al. 2015; Sathre et al. 2015). Ahmadi et al. (2014) estimated a 56% reduction in CO_2 emissions through repurposing a retired EV battery to store off-peak clean electricity to serve peak demand compared to using natural gas fuel for the same purpose. In their study, the magnitude of the CO_2 mitigation is shown to be similar to that of switching from using a conventional car, meaning that the environmental benefits of vehicle electrification could be doubled by B2U.

The future availability of second-life battery capacity was examined and compared with the demand from potential second-use applications (Shokrzadeh & Bibeau 2012; Skarvelis-Kazakos et al. 2013; Neubauer et al. 2015). Neubauer et al. (2015) estimated the annual second-life battery supply to reach 10.8 gigawatt-hours (GWh)/year in 2061 in a low scenario and 101 GWh/year by 2055 in their high scenario. And the total second-life battery deployment was projected to level off at approximately 32.3 GWh of available energy storage by 2063 in a low scenario and 1.01 terawatt-hours (TWh) by 2064 in their high scenario. However, it was forecast that a substantial number of second-life batteries will not become available until 2030 or later and the energy storage market might change significantly between now and then, which could affect the demand and attractiveness of second-life batteries.

These studies demonstrated the economic and environmental feasibilities of B2U under estimated assumptions of certain second use applications. However, a lot of assumptions were used and the results are subject to several uncertain factors such as battery degradation, future new battery price and energy storage market conditions. In addition, most of the studies focused on specific use scenarios of B2U and thus are limited in reflecting the overall benefits of B2U.

b) Trade-off analysis and optimisation

This category of studies focus on the optimisation of battery performance and value over its first and second life (Viswanathan & Kintner-meyer 2011; Lih et al. 2012; Bowler 2014). Through a trade-off analysis of key parameters that influence battery performance (e.g. battery depth of discharge, battery charging/discharging rate etc.), the optimal usage of batteries over the entire battery life and the optimal time to switch from first to second life were investigated. For example, Viswanathan & Kintner-meyer (2011) assumed 15 years for the life of EVs and used up to three batteries for analysis under different regulation service rates and battery state of health (SOH). They also showed that operating the batteries to a low SOH with 65% remaining energy was found to be best for regulation services rates up to $27.5/MWh. A tool was developed to determine optimum operating conditions over SOH and regulation service rates, and the results indicated that as energy storage incentives increase, prematurely removing the battery from the vehicle is favoured to generate the highest revenue potential.

However, since the batteries are normally owned and operated by EV drivers, it is not very likely to manage and optimise the battery performance parameters and decide the switch time for second use in practice. Currently the EV battery owners are not connected to the B2U system and thus they do not benefit from optimising the batteries for second use – it is classic selfish consumer behaviour to just use the battery until it is totally useless. In fact, EV owners could benefit from optimising the battery over its first and second life but they are not rational decision makers – we cannot rely on the EV customers or the market to solve this problem. Alternative battery ownership models, for example, battery leasing, were suggested that facilitate the optimisation of battery operation for dual services in vehicles and energy storage (Viswanathan & Kintner-meyer 2011).

c) Technical and operational analysis

In the third category of studies, researchers investigated various technical issues and operational aspects of B2U that support decision making and battery system performance optimisation. Technical challenges such as battery aging effects, battery standards, thermal and safety management were discussed (Lih et al. 2012; Ahmadi et al. 2014; Strickland et al. 2014). Several studies examined the degradation of the batteries and the remaining battery lifetime under specific second use scenarios (Lih et al. 2012; Neubauer et al. 2012; Ahmadi et al. 2014; Ambrose et al. 2014; Strickland et al. 2014).

Many researchers investigated the operational aspects of B2U including control strategies and system design that support decision-making and optimisation of the second-life battery system performance. Based on the analysis of the aging mechanisms of Europe's first second-life battery system, Gohla-Neudecker et al. (2015) investigated the optimisation of the control strategy for "attaining maxium system performance with minimum battery cell aging to guarantee a long life cycle" (Gohla-Neudecker et al. 2015). Optimisation measures in key parameters such as state of charge (SOC), C-rate and system cell temperature were examined, which provided an analytical basis for deducting an effective control strategy. Keeli and Sharma (2012) developed a rule-based control for peak load management of commercial buildings that determine the size of the battery required and rules to be followed for "charging and discharging the battery which in turn extends the battery lifetime" (Keeli & Sharma 2012). For example, the simulation results in their paper showed that to retain 80% SOC for the batteries, 186kWh of battery storage are needed to achieve 20% reduction in peak load for their target building.

Monhof et al. (2015) examined the design of battery management systems (BMS) that supply data required for B2U decision-making (Monhof et al. 2015). They later did a study that investigated the requirement categories and metrics that govern the fit of the battery and second use scenarios (Beverungen et al. 2016). A decision support system was designed to match second-life batteries with the most suitable second use applications which minimises the technical misfit.

d) Market analysis and business models

Compared with the previous three categories, this group of studies tends to take a wider view across the battery value chain to look at the market and BMs for second-life batteries. Although most B2U investigations were initially motivated by the potential value of second-life batteries, few studies to date have explored how to extract value from B2U. This is a relatively new and unexplored research area.

Among the research that touched on the topic of B2U market and BMs, Lih et al. (2012) investigated "optimal business model for the second use applications of retired EV batteries" and proposed a new sale model – "sell an EV exclusive of the battery but lease it (the battery)". However, this study was not actually investigating the BM of B2U and how value is created and captured from second-life batteries, but more about calculating the profits of the proposed battery leasing model under estimated assumptions. Beer et al. (2012) proposed three different BMs and discussed the added value of EV battery storage capability for second use in building energy management systems (EMSs). However, the three models presented were just comparing different levels of integration of the battery with the building EMSs without actually investigating the value creation and capture from B2U (Beer et al. 2012).

A more recent study by Klör et al. (2015) proposed a conceptualisation of three possible market forms for trading used EV batteries: closed, intermediary-based and open markets (Klör et al. 2015). The proposed market forms were evaluated through a conceptual transaction cost analysis and an empirical inquiry based on semi-structured interviews. The transaction cost analysis of the three scenarios suggested that the market for used EV batteries would likely be a closed one, while the empirical studies indicated an intermediary-based market supported by automobile companies. The new scenario revealed by the interviews indicated that more empirical studies are needed to understand what is actually happening in industrial practices. This study also emphasised the importance of information and data collection and sharing to help remove the uncertainty from markets for used EV batteries and help decision-making in trading.

Bräuer (2016) examined the challenges of B2U from the customer's side and suggested product service systems (PSS) as a promising approach to addressing the issues of quality uncertainty of second-life batteries for customers. Another study by Bräuer et al. (2016) investigated the information asymmetry of B2U using the lemon-market theory and suggested a re-design of BMs for second-life batteries from existing residential storage systems based on new batteries (Bräuer et al. 2016). The development of a service-centered BM was suggested to offer value-added services that compensate the defects of used batteries. Both studies addressed the "so far unsatisfied need to design business models" for second-life batteries and indicated the importance and inadequacy of BM research for B2U.

Challenges of B2U

In all four categories of extant B2U studies, researchers from different fields discussed challenges or barriers that could make B2U difficult. Some investigated technical challenges, for example, non-standardized battery modules (Cready et al. 2003; Williams & Lipman 2011; Lih et al. 2012), uncertain battery degradation during second life (Cready et al. 2003; Lih et al. 2012; Ahmadi et al. 2014; Ahmadi et al. 2014; Elkind 2014; Neubauer et al. 2015; Klör et al. 2015) which could make it difficult to obtain and re-assemble second-life batteries with similar performance (Cready et al. 2003; Williams & Lipman 2010; Gohla-Neudecker et al. 2015). Other technical challenges examined in the literature include the integration of power electronics as well as new energy, thermal and safety management systems for second use (Cready et al. 2003; Lih et al. 2012), implementation of control and battery management strategies that maximise battery value (Ahmadi et al. 2014), and initial vehicle design which could cause difficulties for B2U (Williams & Lipman 2011).

Some researchers discussed economic- or market-oriented challenges. These include uncertainties in economic return and cost competition from new batteries (Elkind 2014; Neubauer et al. 2015), unclear warranty terms and costs (Cready et al. 2003), as well as battery liability issues (Cready et al. 2003; Elkind 2014).

The lack of clear and appropriate B2U regulations was also considered as one of the challenges (Lih et al. 2012). Elkind (2014) regarded the complex and adverse regulatory structures that limit market opportunities and increase costs (e.g. regulations regarding the transportation of used EV batteries which are currently classified as hazardous waste) as one of the key barriers for B2U.

Interestingly, Bräuer (2016) specifically discussed B2U challenges from the customer's perspective. Four major challenges have been identified, namely, a) risks of acquiring a used battery, b) smooth start-up, safe operation, and appropriate battery return, c) customer's cost-performance ratio and d) customer's product experience. The author suggested that those challenges could not be addressed by solely offering the batteries as a product. Instead, new BMs, for example PSS, should be examined to counter the uncertainties from second-life batteries.

In general, the challenges addressed in the literature provide valuable insights in terms of understanding the overall barriers to B2U and how they could be overcome. However, most of the studies are based on propositions rather than empirical investigations. To better understand the challenges that impair the potential value of second-life batteries, more empirical studies are needed to investigate the B2U challenges confronted by B2U stakeholders in practice.

In summary, B2U has attracted increasing attention from both industry and academia. Researchers have been investigating this topic from various aspects to understand the potential of B2U in energy storage to extend the valuable life of EV batteries. The papers selected to be included in this literature review are not exhaustive but could be taken to represent a relatively complete landscape of the current research on B2U.

2.4.3 Comments on the current status of B2U research

B2U as an EOL strategy for EV batteries has attracted increasing attention from researchers in different fields. The literature shows that although the effect of B2U in helping overcome EV first-cost hurdle might be small and is subject to a lot of uncertainties, the broader social and environmental benefits from B2U could be significant (Neubauer et al. 2015) and this optimism deserves further investigation. Technical and operational analysis show that the perceived value of second-life batteries is influenced by a multitude of interdependent factors such as battery degradation during first and second life and battery repurposing cost (Elkind 2014; Neubauer et al. 2015). Trade-off analysis was conducted and the optimisation of control strategies, battery system design and decision support systems were proposed in various studies (Viswanathan & Kintner-meyer 2011; Bowler 2014; Monhof et al. 2015; Gohla-Neudecker et al. 2015).

Despite their importance in the promotion of B2U research, those studies tend to focus on single aspects of specific B2U scenarios which require a lot of assumptions and estimations. Moreover, most of the studies were trying to quantify the potential benefits of B2U from certain specific aspects which required a detailed breakdown of technical, economic or environmental parameters of each process. Due to the complexity and uncertainty of the many interdependent parameters during the early stage of B2U, these studies tend to be limited in certain boundary conditions and estimate assumptions (Bowler 2014).

Recent studies into the BMs of B2U are transitioning to a focus away from discussing the detailed technical, economic or environmental feasibilities of B2U and towards an understanding of the potentials and value of second-life batteries from a broader perspective over the value chain (Bräuer 2016; Bräuer et al. 2016; Klör et al. 2015). These studies tend to be qualitative and are therefore less limited by the requirement to quantify the specific parameters of each process which are uncertain at the early stage of B2U (Bowler 2014). However, the extant studies on the BMs of B2U only touched on the concept of BM without a deep understanding of the value creation and capture from B2U. Rarely based on empirical evidence, these BM studies suggest the need for more empirical studies on B2U to better understand the potential value of second-life batteries through the lens of BMs. For example, Bräuer (2016) suggested examples of service-based BMs to help address customers' challenges in B2U, but the ideas are only based on the literature review without support from empirical evidence.

B2U is conceptualised here as a subset of sustainability and it is expected that most of the B2U literature should be within the overlap of sustainability and B2U. There are some studies that analysed the environmental benefits and energy effects of B2U (Ahmadi et al. 2014; Sathre et al. 2015). However, many B2U studies seemed to start from the wider concept of sustainability but end up with more technical or economic analysis without drawing the important concepts from sustainability into their studies (Gohla-Neudecker et al. 2015). Therefore, the intersection of B2U and sustainability shown in Figure 2.1 is almost blank, which suggests further investigations into B2U that draw on the key concepts from the sustainability field.

The literature review also shows a lack of research on B2U practices. No academic literature has been found so far that addresses the B2U element or business of any automotive or energy companies. The lack of industrial cases in the existing literature suggests the need for more empirical studies to provide practical insights into this emerging research area.

2.4.4 Potential impact of battery second use on the electricity sector

The deployment of B2U in various stationary storage applications including residential energy storage, renewable integration, load levelling, peak shifting have been discussed in the literature (Lacey et al. 2013; Ambrose et al. 2014; Beer et al. 2012; Bräuer et al. 2016; Heymans et al. 2014). Second-life batteries have the potential to provide cost-efficient energy storage solutions at residential, commercial and industrial, as well as grid levels.

2.5 Research gap and confirmed research question

The literature review covers three fields of literature, which are sustainability, BMs and B2U. To provide insights into the research inquiry, studies that are relevant and come closest to the inquiry are discussed in the literature review. Despite the widespread perception of the potential for sustainability benefits to be generated through B2U, little is known about the realities of how B2U stakeholders can better extract value from second-life batteries, especially from sustainability perspectives. There are a few studies on the business models of B2U but they only touched on the concept of BM and offered few insights into the potential value of B2U and how the value could be realized. Moreover, B2U, despite being a sustainability concept, has attracted few studies that draw on the key concepts from the sustainability field such as life cycle thinking and TBL, to help understand the value creation and capture of B2U.

The novelty of the research question is checked against the literature that is closest to answering the question:

How could firms develop battery second use business models based on sustainability concepts to achieve the potential value of second-life batteries?

Sub-questions**:**

1) What are the challenges for B2U and what is the potential value of second-life batteries?

2) How are firms creating and capturing value from second-life batteries through their current BMs?
3) How can firms better develop BMs that draw on sustainability concepts to achieve the potential value of second-life batteries?

The closest literature and the nearest answers to the research questions are summarised in Table 2.3. As shown in the table, the closest papers do not answer the research questions. The gap identified from the literature is the lack of understanding of the business models of B2U that draw on sustainability concepts to investigate how firms create and capture value from second-life batteries. In addition, the lack of B2U industrial cases hinders our in-depth understanding of what is happening in the B2U industry, how companies are developing BMs to create and capture value from second-life batteries as well as the application of existing knowledge to help better develop the BMs. The gap in the current knowledge is therefore confirmed and the research question remains novel. This study aims at filling the research gap by answering the research question.

Table 2.3 Summary of the nearest answers to the research questions

Research questions (RQs)	The most relevant paper	Their contribution and gap
Sub RQ1 What are the challenges for B2U and what is the potential value of second-life batteries?	Bräuer (2016)	It examined the challenges of B2U across the battery life cycle, but the list of challenges was based on a literature review without empirical evidence and the potential value of second-life batteries was not discussed against the challenges.
Sub RQ2 How are firms creating and capturing value through their current BMs?	Bräuer et al. (2016)	It reviewed existing BMs for the German residential battery energy storage systems and suggested a re-design for second-life batteries based on offering value-added services, but did not cover any BMs for second-life batteries based on empirical cases to investigate the value creation and capture from B2U.
	Beer et al. (2012)	It proposed three different BMs to analyse the added value of EV battery storage capability for second use in building EMS, but it just compared different levels of battery integration with the building EMS without investigating the value creation and capture of B2U.
	Klör et al. (2015)	It conceptualized three possible market forms for trading retired EV batteries, namely, closed, intermediary-based and open markets. It provided some insights into possible stakeholder relationships for B2U but did not investigate how stakeholders create and capture value from second-life batteries.

Sub RQ3 How can firms better develop BMs that draw on sustainability concepts to achieve the potential value of second-life batteries?	Bräuer et al. (2016)	It discussed a service-based BM for second-life batteries adapted from current residential storage systems based on new batteries and the effects of value-added services to mitigate information asymmetry and compensate the perceived defects of used batteries. However, the BM is the authors' own proposition without any empirical evidence from existing B2U cases.
	Lih et al. (2012)	It claimed to have designed "optimal business models for second-life batteries" – "sell an EV exclusive of the battery but lease it (the battery)". However, the paper is clearly offering a sales model for EVs, not a BM designed for B2U.

2.6 Key concepts selected for data analysis

Based on the literature, five key concepts are selected in order to help analyse the data in this study. The chosen concepts thus provide the basis of analysis that help investigate the research question: **How could firms develop battery second use business models based on sustainability concepts to achieve the potential value of second-life batteries?** The five key concepts are selected from the three bodies of literature based on their relevance, importance and applicability. The five concepts are: a) Triple Bottom Line (TBL), b) life cycle thinking, c) multi-stakeholder perspective, d) activity system perspective of BMs, and e) value creation and capture. The author regards the chosen concepts as the most relevant and helpful ones to analyse the BMs of second-life batteries.

TBL

As discussed in Section 2.2, the concept of TBL extends the traditional financial bottom line to a sustainability perspective encompassing not only economic, but also social and environmental aspects of performance (Elkington 1997). This concepts requires a fundamental change in the mindset to think about value from a broader view, which allows various forms of value (economic, social and environmental) to be identified. Many authors claim the importance of integrating TBL into BM development in order to generate value from sustainability (Stubbs & Cocklin 2008; Hart & Milstein 2003). The TBL concept is important for the context of this study, because B2U itself is about generating value from "being more sustainable". Thinking from the TBL perspective helps integrate sustainability into the core of the B2U business.

Life cycle thinking

Life cycle thinking is an important concept in the fields of circular economy, sustainability and more recently, sustainable BMs (Bocken et al. 2014). As discussed in the previous sections, this concept considers the entire product life cycle, from the BOL (extraction, design and production) to the MOL (use and maintenance), and then to the EOL (reverse logistics, reuse, recycling, and disposal) (Jun et al. 2007). For example, a second-life battery was once at the EOL stage of its vehicle lifecycle (first life) but is then the BOL for a second-life application. The once retired batteries will start a new life cycle in the second use applications. Life cycle thinking allows the value analysis of second-life batteries to be linked backwards to their first life and forwards to the EOL to help better understand value creation and capture from B2U.

Multi-stakeholder perspective

Multi-stakeholder perspective is regarded as a key concept in sustainable BMs (Stubbs & Cocklin 2008; Short et al. 2013). As discussed in the previous sections, this concept considers society and environment as key stakeholders and emphasises the importance of multi-stakeholder engagement and collaborative partnerships among stakeholders (Stubbs &

Cocklin 2008). In the case of B2U, the concept of multi-stakeholder becomes even more important in that a wide range of stakeholders could be involved to transform retired EV batteries into second-life energy storage batteries. Those stakeholders might play different roles at various stages of the second-life battery life cycle. The multi-stakeholder perspective helps analyse where potential value opportunities could be identified and how value of second-life batteries is created and shared among various stakeholders at the system level.

Activity system perspective of business models

As discussed in Section 2.3.1, the activity system perspective of BMs provides an analysis approach at the system level which "transcend the focal firm and span its boundaries" (Zott & Amit 2010). The activity system perspective is proposed as a useful conceptualisation in the BM literature that emphasises systemic and holistic thinking (Zott & Amit 2010). In the case of B2U, multiple stakeholders could be involved across various stages of the battery life cycle. A system-level approach is thus required that allows multiple stakeholders and system-level value to be considered in the BM analysis. The activity system perspective provides a systemic approach to analysing the relationships and interactions among key stakeholders that develop the BMs.

Value creation and capture

The concept of value creation and capture is extensively used within the BM literature to analyse BMs (Amit & Zott 2001; Amit & Zott 2012; Chesbrough & Rosenbloom 2002; Chesbrough 2007). As discussed in Section 2.3.1, although consensus has yet to be reached regarding a widely accepted definition or framework for BM, converging themes are value proposition, value delivery, value creation and capture which are sometimes overlapped (Chesbrough & Rosenbloom 2002; Richardson 2008; Magretta 2002; Johnson et al. 2008). In this study, this concept is used to help analyse the BMs developed by key stakeholders: how they create and capture value from second-life batteries.

These five key concepts have been selected from the literature and are used to build an analytical framework in Chapter 3 to help analyse the case study data on the BMs of second-life batteries. The novelty of this analytical framing is that normally only one or two concepts such as value creation and capture or activity system perspective are used to help analyse BMs, but in this study, five key concepts from the three bodies of literature are adopted to analyse the data. This is due to the complex nature of the research inquiry and the desire to use five separate lenses to study the phenomenon is intended to enable new insights and to be helpful in analysing the data to answer the research question.

2.7 Summary

This chapter presented the existing knowledge and discussions that are most important and relevant to the research inquiry. Researchers from various fields have shown extensive interests in the feasibility and benefits of B2U but little evidence or understanding is found on how companies can better extract the potential value from second-life batteries. This chapter identified the research gap in the literature and confirmed the research question.

3 Research Methodology

This chapter presents the research design and the decisions made by the researcher to develop a reasonable approach to answering the research question and achieving the research objective. The rationale behind the research method adopted in this study is explained, which includes the selection of an underlying philosophical position, a fitting methodological approach, and suitable research methods. The research design explains how data are collected and analysed. The quality of the research design is then evaluated and limitations addressed. This chapter also presents an analytical framework based on key concepts drawn from the literature to help analyse the empirical data from the case studies.

3.1 Philosophical positioning

Two fundamental concepts in the philosophy of science are ontology and epistemology. Ontological and epistemological viewpoints build up the philosophical thought underlying any form of research (Campbell 1988). According to Easterby-Smith et al. (2012), ontology is concerned with “the nature of reality and existence” while epistemology is about “the best ways of enquiring into the nature of the world”. Two contrasting views of the philosophical positioning in social science research take the central stage – positivism and social constructionism. A positivist approach to research involves observation, measurement and verification while social constructionism focuses on “different constructions and meanings that people place upon their experience” (Easterby-Smith et al. 2012). The former is more objective, associated with observation and generalization whereas the latter is subjective and interpretive, and includes understandings that people give to their surroundings. The major contrasting implications of the two positions are summarised in Table 3.1 (Easterby-Smith et al. 2012).

Table 3.1 Contrasting implications of positivism and social constructionism

	Positivism	**Social Constructionism**
The observer	must be independent	is part of what is being observed
Human interests	should be irrelevant	are the main drivers of science
Explanations	must demonstrate causality	aim to increase general understanding of the situation
Research progresses through	hypotheses and deductions	gathering rich data from which ideas are induced
Concepts	need to be defined so that they can be measured	should incorporate stakeholder perspectives
Unit of analysis	should be reduced to simplest terms	may include the complexity of 'whole' situations
Generalization through	statistical probability	theoretical abstraction
Sampling requires	large numbers selected randomly	small numbers of cases chosen for specific reasons

(Source: Easterby-Smith et al. 2012, p.24)

Researchers can choose from various positions and methods to carry out their research. This study starts with a complex, real-world problem identified in the B2U industry and aims to improve understanding of the value of B2U. It is difficult to observe, measure or verify the value of B2U (especially environmental and social value) because the value is given meaning by people based on their own understandings of B2U in their specific contexts. Therefore, to understand the value of B2U and how firms develop BMs to create and capture value from B2U requires gathering ideas and perspectives from various stakeholders. The exploratory and interpretive nature of this study on the BMs for an emerging technology (B2U) and the inclination towards generating a description, justify the philosophical positioning of social constructionism, and the aim of this research is to increase general understanding of the value of B2U and build new knowledge from empirical evidence. Therefore, the author chooses the philosophical view of social constructionism for this research.

3.2 Methodological choice

Different research methods are appropriate for different research objectives. The two dominant ways to make contributions to theories are by theory testing and theory building. Theory testing follows the deductive model where researchers formulate hypotheses before testing them with observations; while researchers in theory building begin with observations to generate theory through inductive reasoning (Colquitt & Zapata-Phelan 2007). Based on the state of research (nascent, intermediate and mature), Edmondson & McManus (2007) provides a range of methodological choices and suggests that a qualitative approach is appropriate for theory generation from nascent research while a quantitative approach is appropriate for testing or refining well-developed theories, and a hybrid approach (both qualitative and quantitative) is recommended for intermediate research introducing new constructs or propositions to provisional theories.

Qualitative research takes a holistic and comprehensive approach to the study of phenomena and are suitable for research areas where little knowledge has yet been generated (Corbin & Strauss 2014). Despite the increasing number of publications on B2U, few offer insights into the value generation from B2U based on empirical evidence and few could provide theoretical foundations for this research. The understanding of the value of B2U is still very poor and little knowledge has been generated in terms of extracting the value from second-life batteries. This study aims to addresses the complex, real-world problem identified in the emerging B2U industry and generate new knowledge to help extract value from second-life batteries through innovative BMs. Besides, the research question "How could firms develop battery second use business models based on sustainability concepts to achieve the potential value of second-life batteries?" requires a close examination of the BM development which involves the interviewee's personal experiences and understanding. And at this embryonic stage of the B2U development which is plagued with uncertainties, qualitative research tends to take a wider and holistic view on the potentials related to the value of B2U. Thus, this research adopts an exploratory, qualitative theory building approach.

3.3 Research methods

Research methods are “techniques or procedures used to collect and analyse data” and should be selected based on research questions (Grix 2002). In this research, the case study method has been adopted to help answer the research question and achieve the research objective.

Regarding when to use what method to answer what type of research question, Yin (2013) developed a widely used table for the selection of different research methods (Table 3.2). The reasons for choosing case study method for this research are explained as follows. Firstly, case study method is suitable for answering “how” and “why” questions in unexplored research areas (Edmondson & McManus 2007). Second, case study is recommended for research that “desire to understand complex social phenomena” because it “allows investigators to focus on a ‘case’ and retain a holistic and real-world perspective” (Yin 2013). Moreover, case study is suggested as an approach for exploratory theory building research because cases can provide novel, testable and empirically-valid insights (Eisenhardt 1989). Deeply embedded in rich empirical data, case study method is likely to produce theory that is “accurate, interesting and testable” (Eisenhardt & Graebner 2007).

Table 3.2 Relevant situations for different research methods

Method	Forms of research question	Requires control of behavioral events?	Focuses on contemporary events?
Experiment	How, why?	Yes	Yes
Survey	Who, what, where, how many, how much?	No	Yes
Archival analysis	Who, what, where, how many, how much?	No	Yes/No
History	How, why?	No	No
Case study	How, why?	No	Yes

(Source: Yin 2013, p.9)

In this thesis, the main research question “How could firms develop battery second use business models based on sustainability concepts to achieve the potential value of second-life batteries?” is a “how” type question. And this research studies a complex, contemporary phenomenon over which the researcher has no control. This research studies the emerging B2U industry and aims to gain explorative, qualitative, real-life insights that help better understand the value generation logic for B2U and to build theories in this nascent research area. The literature has addressed the importance of BM research in the B2U context but provided little theoretical foundation and empirical evidence. The importance of this research area, the lack of viable theory and empirical evidence, and the explorative and emerging nature of this research topic justify case study as a suitable method for this research.

3.4 Research design

This research chooses the philosophical position of social constructionism and adopts qualitative case studies as the principle research method. Based on Yin’s book (Yin 2013) and Eisenhardt’s paper (Eisenhardt 1989), the research design for this study include: how cases are selected and what sources of data are included, how and what data are collected, and how data are analysed to answer the research question and fill the research gap. The research design is then evaluated and limitations addressed.

3.4.1 Presentation of the case study process

This section presents the overall case study process. As shown in Figure 3.1, the process contains three phases from define and design, data collection and analysis, to data synthesis and conclusion. Case studies will be used to identify the value creation and capture patterns of various B2U stakeholders, which subsequently enhances the existing knowledge. In the phase of define and design, the unit of analysis for this study is defined as the business model of B2U. Based on the unit of analysis, cases are selected and data collection protocol designed. In the second phase, data are collected in each of the case study and single case analysis is conducted thereafter. The single case findings are then compared across all the cases for cross-case analysis. In the final stage, the findings are reflected and synthesised from which themes and conclusions are drawn.

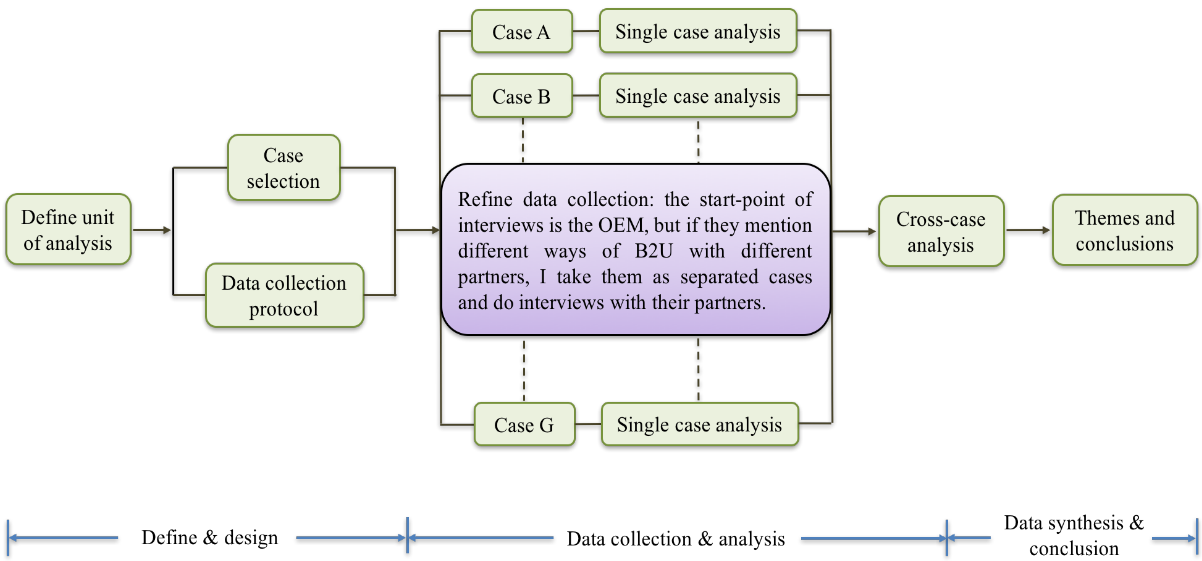

Figure 3.1 Presentation of the case study research process

It is worth noticing that the data collection process is continuously refined based on the data collected. For example, the initial plan for the interviews is with the original equipment manufacturers (OEMs) of EVs because it seems obvious that the OEMs will be responsible for EOL batteries and they would most likely develop BMs to generate value from second-life batteries. However, after a few interviews, it was found that only interviewing the OEMs is insufficient to understand the value generation from B2U. The batteries will be repurposed for energy storage applications and the value generation mechanism could not be fully understood without analysing the BMs of the OEM's energy storage partners. And the OEMs might have different BMs of B2U with different partners. To understand how value is generated from second-life batteries and how the OEMs create and capture value through different interactions with their partners, it is necessary to collect data from their energy storage partners as well. Thus, the data collection plan was refined to also include interviews with their energy storage partners instead of just interviewing the OEMs.

3.4.2 Case selection and data sources

The required number of cases for research of this type is academically debatable. However, Eisenhardt (1989) suggested that 4-10 cases in case methodology are understood to be typical and usually work well. In this study, the cases were selected on the basis of theoretical sampling as well as the review of industry practice. As opposed to statistical sampling, cases selected using theoretical sampling are not expected to be representative. Rather, they are supposed to offer theoretical insight and illuminate particular relationships to help extend the logic of theoretical constructs. The cases selected for this research are therefore chosen for their potential to "reveal an unusual phenomenon, replicate findings from other cases, and elaborate emergent theory" (Eisenhardt & Graebner 2007).

In the nascent stage of B2U, only a handful of B2U cases are available worldwide to provide data to study the BMs of second-life batteries at a commercial level. Up until this moment, most of the B2U projects are still in the planning, piloting or demonstration phases that are often more focused on technical or economic feasibilities. The case studies analysed in this research are based on theoretical sampling as well as practice-oriented aims to obtain the most valuable insights possible into B2U business models. The cases chosen for this research have been identified through a review of the academic literature, published company reports as well as specialised industry news.

Seven case studies are selected from the few existing B2U examples that have passed the phases of technical piloting or demonstration to reach the BM development or early commercialization stage. As explained in the previous section, the author aimed to interview in each case study not only the OEM but also their major energy storage partners. The author failed to access one of the OEMs but managed to interview their energy storage partner who claimed to be the only B2U partner of that OEM currently (case V). Interview invitations to energy storage partners of two OEMs were rejected (case IV and VI). The author tried to access the two energy storage companies through the OEMs but they described their partners' BMs and said it is enough to talk to them (the OEMs) to understand the BMs of their partners.

This study covers all the known B2U business models happening in the real world. It should be noted that the same OEM (or their different international divisions) might appear in multiple cases because they could have several B2U business models in parallel with different energy storage companies, which are treated here as separate cases. The seven case studies are summarised in Table 3.3.

In this research, the main sources of data are in-depth interview data collected from organisations involved in the business models of B2U. Due to the very emerging nature of B2U, the interview data are complemented by data from other sources such as academic papers, company reports, press release, consulting reports, presentations, and industry news.

Table 3.3 Summary of the seven case studies in this research

Case No.	Company name	Stakeholder role	Region	Interviewees' position
I	A	OEM	North America	General Manager
	B	Energy storage/ B2U system provider	California	CEO and Co-founder
	C	Lifecycle management	US	President and Founder
	D	B2U joint venture	Japan	President General Manager, Planning Div.; General Manager, R&D Div.
II	A	OEM	North America	General Manager
	E	Energy storage/ B2U system provider	California	COO
III	A	OEM	Europe	General Manager, Zero Emission Strategy; Manager, V2G and Stationary Storage; Expert Leader, Technology Planning Dept., Advanced Engineering Div.
	F	Power/energy management	Europe	Vice President of EMEA Marketing
IV	G	OEM	North America	Manager, Connected eMobility
			Germany	Program Leader, Battery 2nd Life; Head of Development Stationary Storage Systems
V	I	Energy storage	Germany	Managing Director
VI	J	OEM	France	Program Manager, Energy Services
VII	L	OEM	Japan	Project General Manger, New Business Planning Div.; Project Manager, Environmental Affairs Div.; Group Manager, Planning Dept.

3.4.3 Data collection and analysis

Semi-structured interviews are adopted as the appropriate approach to data collection for this research. The interview questions were slightly tailored to the specific situations of the case companies and interviewees, but followed the same template in general. An exploratory semi-structured interview protocol was used to guide data collection and increase the reliability of the research (Yin 2013). The semi-structured interview protocol follows a systematic structure in order to guarantee the reliability and quality of the data but in the meanwhile also allows the flexibility for interviewees to explore particular themes or further responses that might generate interesting insights.

The confidentiality and research purposes were made clear and guaranteed at the start of each interview. The interviews generally lasted between 30min and 3 hours. The questions followed a conversational approach which were open-ended and the structure of the interview allowed respondents to expand on subjects of their interests. The interviews were all conducted in English. Several interviews in Japan involved the presence of a translator who is an academic expert in the field. Most of the interviews were conducted at the company sites and the researcher has travelled to Japan, the US, France, Germany and China to collect data. For example, the researcher spent four months in Japan with one of the automotive companies in order to conduct in-depth interviews with the case companies. Data were collected between December 2014 and November 2016. Over this 24-month period, 25 interviews were undertaken of which 13 (conducted with 19 interviewees) were finally selected for the case study analysis. The interviews were conducted with key informants in each case organisation. The complete list of interviews can be found in Appendix A.

The questions asked in the interviews followed a general structure including the introduction to the company, the key elements of a business model (customer value proposition, value creation, value network position, value capture). Interviewees were also asked about the motivations, the benefits, the major challenges, as well as the regional context (e.g. policy and regulations) for developing B2U. An example of the interview questionnaires can be found in

Appendix B. Individual case study reports were sent to the interviewees for review and the researcher received comments from 9 companies which were included in this thesis. Because some of the companies prefer not to be named publicly, the author keeps all the interview companies anonymous for consistency.

The interviews selected for the data analysis produced 25 hours and 18 mins of recordings, resulting in a large amount of transcribed data (64,887 words of transcripts). All the interviews were recorded and transcribed word for word to try to avoid bias. In order to be thoroughly familiar with the data, each interview was listened and the transcript read at least twice before commencing the analysis (Cassell & Symon 1994). An analytical reflection of the data was carried out by the identification of emerging patterns (Yin 2013). According to Miles et al. (2014), coding is “deep reflection”, “deep analysis and interpretation” of the data’s meaning and codes are “labels that assign symbolic meaning to the descriptive or inferential information compiled during a study”. In this research, the data coding was carried out using Excel. B2U motivations, challenges, benefits and the business model elements (customer value proposition, value creation, value network position, value capture) were the main coding categories for each case study. The single-case findings were then analysed across all the seven cases for cross-case findings and synthesis. The data analysis results are presented in Chapter 4, 5 and 6.

3.4.4 Quality of the research

The four criteria for judging the case study research quality proposed by Yin (2013) are: construct validity, internal validity, external validity and reliability. A number of case study tactics are also proposed to enhance the quality of case study research (Table 3.4). These criteria are used to assess the quality of this research.

Table 3.4 Assessing criteria and tactics for case study research

Criteria	Definition	Case study tactics
Construct validity	Correct operational measures for the concepts studied	• Use multiple sources of evidence • Establish chain of evidence • Have key informants review draft case study report
Internal validity	For explanatory/causal studies only: established causal relationship where certain conditions are believed to lead to other conditions	• Do pattern matching • Do explanation building • Address rival explanations • Use logic models
External validity	Generalizability of a study's findings beyond the immediate study	• Use theory in single-case studies • Use replication logic in multiple-case studies
Reliability	Repeatability of the operations beyond this study	• Use case study protocol • Develop case study database

(Source: Yin 2013, p.45)

This study uses multiple sources of evidence to support claims about B2U stakeholders' BMs of second-life batteries. For example, companies would talk about their competitors' or partners' BMs, and supplementary data such as industrial and consulting reports are used to help ensure the construct validity. Besides, the findings are exposed to peer reviews from both academia and industry through international conferences and symposiums.

According to Yin (2013), the internal validity only applies to explanatory study where causal relationships are studied. Since this research is exploratory in nature, aiming to explore the emerging B2U business models through which insights are drawn to help better extract value from second-life batteries, this is not a causal relationship study so internal validity is not a concern for this research. Even though internal validity does not apply to this study, some of the techniques were still used to help improve the general quality. For example, the author tried to look for patterns that improves general understanding of the selection of B2U business models.

To make the research generalizable, the case studies have been chosen to be as diverse as possible which include various B2U business models even those developed by the same stakeholder. Each case study includes the same key B2U stakeholders and is analysed following the same analytical framework (developed in Section 3.5). This replication logic in the selection and analysis of cases helps ensure external validity in this research. The final framework is also generalizable beyond the cases in this research to other B2U stakeholders. In addition, the final framework can be applied to the analysis of BMs in other second-use technologies, such as fuel cells and smart meters, in future research.

The reliability of this research is ensured with the interview protocol explained in Section 3.4.3. Structured processes are followed during the data collection and analysis so that another interviewer performing the same case interviews could come to the same conclusions.

3.5 Analytical framework for analysing the business model of second-life batteries

3.5.1 Objectives of the analytical framework

In this study, the purpose of building the analytical framework is to help analyse the data in the empirical case studies. The objectives of the analytical framework are:

- to target specific concepts which might deliver insights that are useful to answering the research questions;
- to provide a common language in this study to describe and analyse B2U business models in the empirical case studies.

3.5.2 Rationales for the analytical framework

As mentioned in Chapter 2, there is a lack of general agreement or conceptual consistency on the BM definition or its constructs. This study does not aim to give another definition of BM, but to draw on key concepts from the three bodies of literature to build an analytical framework that help analyse the BMs of second-life batteries in this research. As discussed in Section 2.4.5, five concepts were chosen from the literature that form the basis for analysing the BMs of second-life batteries. The five concepts are further developed and synthesized to construct the three rationales that form the logic of the framework. The three rationales are: (a) level of analysis: activity system of second-life batteries; (b) business model analysis and description: the "4V model"; (c) integration of sustainable value. The process of the framework development is shown in Figure 3.2.

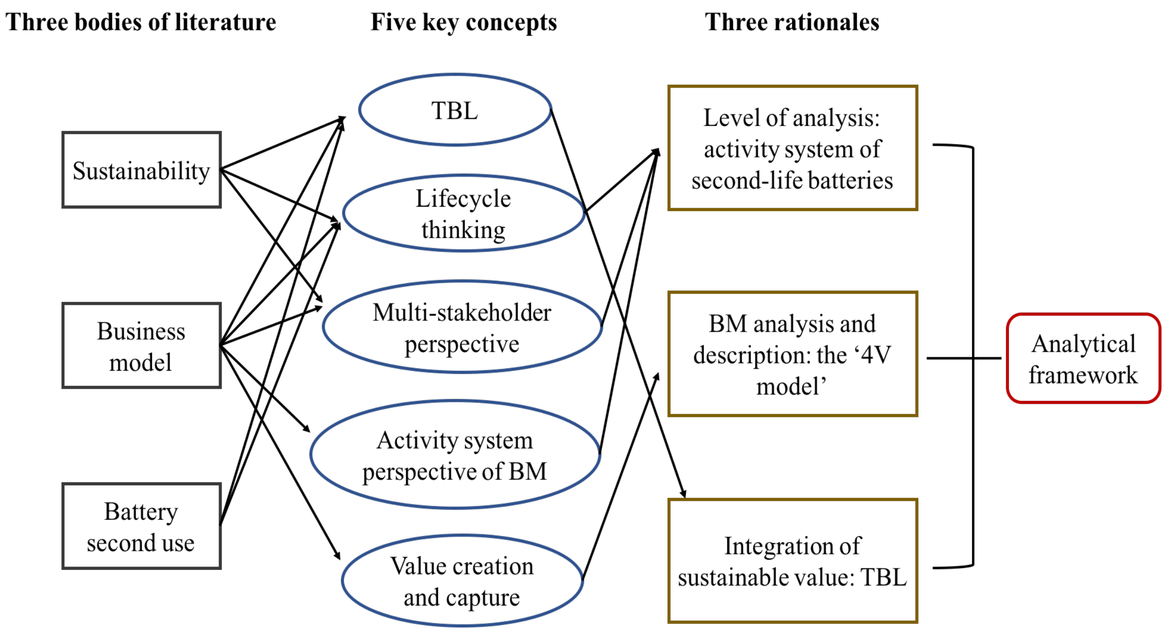

Figure 3.2 Development of the analytical framework

Rationale 1. Level of analysis: Activity system of second-life batteries

This rationale is based on the concepts of life cycle thinking, multi-stakeholder perspective and activity system perspective. The activity system perspective of BMs is that they "transcend the focal firm and span its boundaries" (Zott & Amit 2010) which provides an approach to analysing BMs at the system level. The life cycle thinking and multi-stakeholder perspectives allow various stakeholders at different stages of the battery lifecycle to be considered in BM analysis. In this study, the BM analysis will remain technology-centric rather than firm-centric: the focus of analysis in this study is the value of second-life batteries and the BM analysis will follow the technology of second-life batteries instead of staying with a focal firm. In this study, Zott & Amit (2010)'s activity system perspective is further developed to integrate the concepts of life cycle thinking and multi-stakeholder perspective.

The rationale explains the level of analysis in this study: the activity system of second-life batteries is not just a set of activities conducted for a 'focal firm', but the set of key value creation activities that transform second-life batteries into the final solutions for the end-customers where the value of second-life batteries is finally delivered. This rationale explains that the BM analysis will not necessarily remain with a particular firm, but might include the BMs of multiple stakeholders depending on their roles, relationships and interactions in the activity system.

Rationale 2. Business model analysis and description: the '4V model'

The '4V model' for BM analysis is itself based on the concept of value creation and capture. As mentioned in Section 2.5, there is a convergence in key themes of BM research. Based on the value creation and capture concept, a '4V model' is developed to help analyse and describe BMs of key B2U stakeholders in this research. The '4V model' include: customer value proposition – what is offered to the customer; value creation – how the firm leverage its resources and capabilities to create value for customers; value network position – how the firm positions itself in the value network; and value capture – how the firm benefits through delivering the value to the customers.

Rationale 3. Integration of sustainable value

This rationale is based on the concept of TBL. As discussed in Chapter 2, sustainable value does not only include economic profit, but also social and environmental benefits (J.

Elkington 1997). For B2U, which is considered to be a sustainable practice itself, the benefits provided by the economic, social and environmental aspects of sustainability should be taken into account to better analyse the value of second-life batteries. This rationale allows the social and environmental value, in addition to the economic value, to be integrated into BM analysis for second-life batteries.

3.5.3 Building the framework

The three rationales form the logic of a framework for analysing the BMs of second-life batteries: to analyse the BMs at the system level through the activity system of second-life batteries; to illustrate the BMs of key stakeholders using the '4V model'; and to allow three dimensions (economic, social and environmental) of sustainable value to be considered during BM analysis. The three rationales are integrated and synthesised to construct the analytical framework in this research.

The schematic illustration of the analytical framework is shown in Figure 3.3. As explained in the previous section, the BM analysis will remain technology-centric and follow the technology of second-life batteries instead of staying with a focal firm. "S1, S2...Sn" are the key stakeholders involved during multiple stages of B2U development from the battery, to the system and to the final solutions to the end-customers. It could be one stakeholder all the way through or involve different players. "P" represents the partners of the key stakeholders. The BM of each key stakeholder is analysed using the "4V" model, the value proposition, value creation, value capture and value network, which forms the unit of the activity system of second-life batteries. The economic, social and environmental aspects of sustainable value are used to study the BMs. This analytical framework is used in Chapter 4 to help analyse the empirical data in the seven case studies.

Apart from second-life batteries, the analytical framework could also be used for other technologies that seem to have a more than reasonable amount of value for a second-life application at the end of their first life.

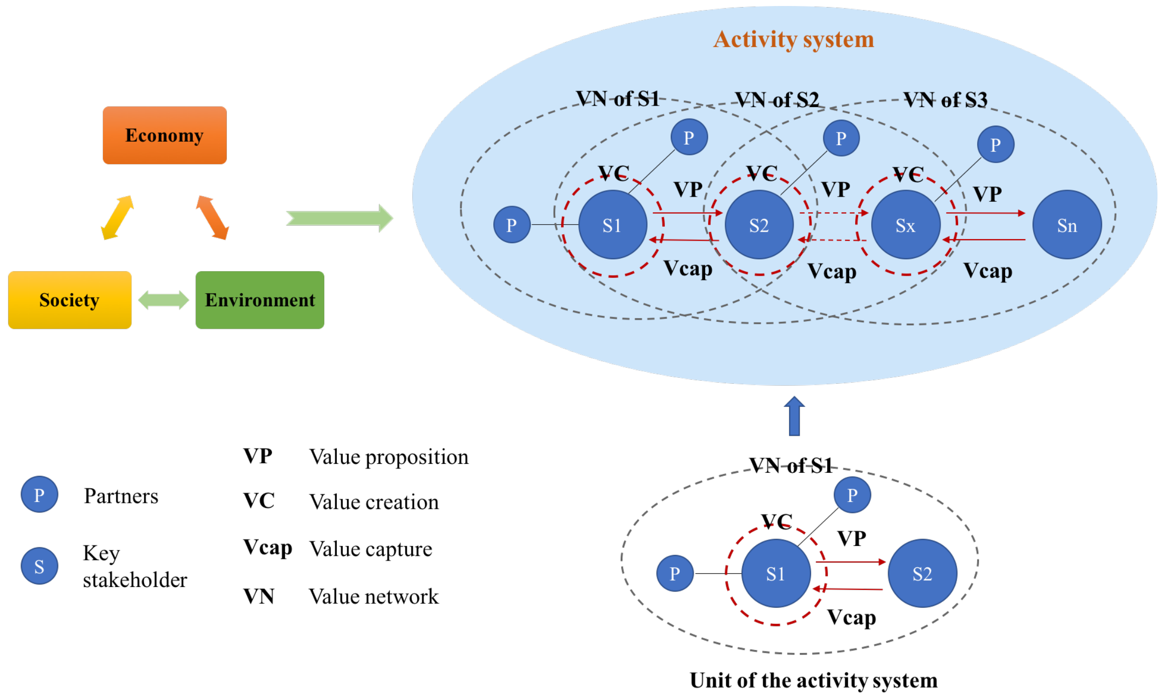

Figure 3.3 Schematic illustration of the analytical framework

3.6 Summary

This research takes the philosophical position of social constructionism, and uses case study method to explore the emerging B2U business models developed by B2U stakeholders to create and capture value from second-life batteries. The research quality is verified against four criteria, which are construct validity, internal validity, external validity and reliability. An analytical framework is also developed to help analyse the case study data on B2U business models in Chapter 4.

4 Case studies

4.1 Chapter overview

This chapter presents an overview of the case studies selected to showcase how manufacturing firms are developing BMs for second-life batteries. The chapter provides context on the key actors involved in each B2U business model case study. The aim is to present a comprehensive picture of all the elements relevant to understand B2U business models. Findings from the data analysis of the seven individual case studies are structured as follows: each case is presented in turn with a brief introduction to the major stakeholders involved, followed by an analysis of the motivations, benefits and challenges of B2U. The BM is then studied using the analytical framework developed in Section 3.5 and reviewed. By integrating these often separately studied pieces of information, the chapter seeks to produce a more accurate understanding of how firms interact and develop B2U business models to create and capture value from second-life batteries.

In the nascent stage of B2U maturity world-wide, only a handful of B2U cases are available to provide data to study BMs of second-life batteries at a commercial level. Most of the B2U projects are still in the planning, piloting or demonstration phases that are often more focused on technical aspects. This research has attempted to encompass all the existing B2U cases for a comprehensive BM analysis. As mentioned in Chapter 3, the seven case studies are selected from the few existing B2U examples that have passed the phases of technical piloting or demonstration to reach the BM development or early commercialization stage. Taken together, the seven case studies are able to present a reasonably complete picture of the emerging B2U industry. A list of the case studies and the companies included in each case study is presented in Table 4.1.

Table 4.1 Distribution of the case study companies

Case No.	I	II	III	IV	V	VI	VII
Company	A B C D	A E	A F	G	H I	J K	L

4.2 Case study I

4.2.1 Introduction to case I

Company A is a Japanese multinational automobile manufacturer who has been leading the global EV sales market. Company A is also among the first OEMs world-wide to commercialize second-life batteries. To get a deep understanding of how Company A develops BMs for second-life batteries, the researcher spent four months at Company A (Japan), visited three key labs and two factories, attended over ten meetings, had daily conversations and more than twenty interviews with both engineers and managers and was introduced to all the key actors involved in their B2U businesses. Since Company A has been running multiple B2U business models in different markets and regions with various partners, the researcher also visited and interviewed people from Company A in North America and Europe, as well as their key partners in energy storage. Five in-depth interviews were conducted with the most relevant persons in Company A across Japan, North America and Europe. Due to the large differences between these BMs, they are presented in this thesis as individual case studies (case I, II and III).

This case study (case I) presents one of the B2U business models of Company A (North America), in which three major stakeholders are involved: the OEM (Company A), an energy storage company (Company B), and a distributor/lifecycle management company (Company C). Apart from Company A, the other two companies were also visited and in-depth interviews with the most relevant persons in these companies conducted.

As a pioneer in zero-emission mobility, Company A made history with the introduction of their first EV model in 2010 as the “first affordable, mass-market, all-electric car” launched globally. Company A intends to deliver a holistic approach to achieving “zero” in battery EVs, and B2U is a part of that initiative. Company A has conducted multiple research projects and field tests to repurpose used EV batteries through Company D, a joint venture founded by Company A and another Japanese company who is a silent partner. Company D was created specifically to enhance EV sustainability for Company A through repurposing the second-life batteries in various energy storage applications. Company D has been testing the technical and economic feasibilities of B2U in various post-vehicle applications across different regions. In the US, however, Company D does not have a separate company yet. They operate as a department of Company A (North America).

Company B is an energy storage start-up founded in 2014 in California, USA. Company B has been working on scalable energy storage systems to solve the “pain points” of customers in the energy market, especially in niche markets. Company B started when they saw the problems in EV charging: the high cost of charging infrastructure and the under-utilization of charging stations. To solve those problems, Company B created their first product, an intelligent mobile charging system composed of second-life EV batteries. As a flexible and cost-effective EV charging alternative, this solution allows customers to avoid expensive and tedious construction projects for charging infrastructure and optimize their electricity bills through intelligent energy management.

Company C is a battery lifecycle management start-up founded in 2014 in the US. Company C provides repair, remanufacturing, refurbishing, and repurposing services for battery packs that were used in hybrid and electric vehicles. Company C aims to help vehicle OEMs optimize the lifecycle management of their battery pack inventory and maximize the value. They offer a variety of services to the OEMs including battery quality analysis, logistics management, battery repair and refurbishment for redeployment in vehicles, repurposing (second use) for non-automotive applications, and recycling management.

The reasons for choosing this case study is that Company A has been leading the EV sales market globally and expects that a huge amount of second-life batteries will come back in the near future. Company A started B2U through the joint venture Company D even before the launch of their first mass-market EV model, making Company D the first company established to specifically tackle B2U issues and commercialize second-life batteries. Company B is, using the words of its CEO and co-founder, "*the first company in the world that commercially deploys 2nd-life batteries and makes money on it*" (E-1). In this case, Company C is a new stakeholder, serving as the connection between Company A and D and providing lifecycle management services to both sides.

This case study presents how these key stakeholders interact and develop BMs to transform retired EV batteries into valuable storage batteries and energy services for the end-customers. In this case, Company A sells retired EV batteries to Company C who collects the batteries and stores them at their own facility. After testing and grading the batteries, Company C sells graded battery modules to Company B. Company B then integrates the second-life batteries into their storage systems and provides mobile EV charging services to the end-customers.

In this case study, in-depth interviews were conducted with the manager of battery business unit and the general manager of EV operations of Company A (Japan), the general manager of Company A (North America), the CEO and co-founder of Company B, the president and founder of Company C, as well as the president and two general managers of Company D (Japan). The interviews in this case produced 11 hours of recordings which were then transcribed. In addition, at each interview or meeting, observations were made and notes taken, forming additional data. The transcription, observations and notes provided the main sources of data, supplemented by secondary data from documentation e.g. company reports and newspaper articles. The data were then coded and analysed, with the key information regarding B2U motivations, benefits and challenges, as well as the BM development extracted. The detailed list of interviews in this case study can be found in Table 4.2.

Table 4.2 List of interviews: Case study I

<table>
<tr><th>Company</th><th>Stakeholder role</th><th>Region</th><th>Interviewees' position</th><th>Reference code</th><th>Time (mins)</th></tr>
<tr><td rowspan="2">A</td><td rowspan="2">OEM</td><td>Japan</td><td>Manager, battery business unit;
General manager, EV operations</td><td>O-1-1</td><td>125</td></tr>
<tr><td>North America</td><td>General manager</td><td>O-1-2</td><td>127</td></tr>
<tr><td>B</td><td>Energy storage</td><td>California</td><td>CEO and co-founder</td><td>E-1</td><td>132</td></tr>
<tr><td>C</td><td>Distributor/ Lifecycle management</td><td>US</td><td>President and founder</td><td>L-1</td><td>38</td></tr>
<tr><td rowspan="2">D</td><td rowspan="2">B2U joint venture</td><td rowspan="2">Japan</td><td>President</td><td rowspan="2">BJV-1</td><td>105</td></tr>
<tr><td>General manager, planning division;
General manager, R&D division</td><td>131</td></tr>
</table>

4.2.2 B2U motivations, benefits and challenges

This section presents why stakeholders in this case study develop solutions for second-life batteries, what are the envisioned benefits and what challenges they have confronted or expected for B2U.

B2U motivations

When it comes to why companies develop B2U, the general manager of Company A (North America) said: "*We look at secondary use of batteries trying to provide benefit back to the EV programme…the idea is to help improve the economics of EVs whether it means delivering a* *lower EV purchasing price to consumers or improving the economics for us by having additional revenue opportunities*" (O-1-2). It can be seen from the large amount of confirming data from other interviewees that the most important B2U motivation for Company A is to benefit the EV programme by generating additional revenues from second-life batteries. There were no notable rejections of EV economics as the motivation in the data.

Company B aims to "*create energy storage systems to solve the pain points in niche markets*" (E-1). Their first targeted market is EV charging because they saw the problem: "*EV charging is difficult. You need a construction project…you have underutilization of your parking (charging) stations because people will park their car at the spot and keep them there all day…*" (E-1). As a young start-up, Company B manages to survive in the competitive energy market through experimenting with niche markets and reducing the cost as much as possible. According to Company B: *"What we pay for their (Company A's) batteries is definitely less than new batteries*" (E-1). The interview data suggest that the B2U motivation for Company B is that second-life batteries are currently much cheaper than new batteries, which allows them to reduce the system cost to provide cost-effective energy storage solutions to quickly enter the market.

For Company C, B2U is an integral part of their battery lifecycle management services. According to the president and founder of Company C: "*The purpose of our business is we want to extend the economic life of battery packs*" (L-1). By providing relevant B2U services (e.g. logistics, battery testing and grading), Company C profits from their integrated battery lifecycle services. As said by the interviewee: "*We try to do everything integrated…because if it is all integrated we have better chances to make it work economically*" (L-1). The data show that the motivation for Company C to take part in the B2U business is to extend the economic life of battery packs and integrate their battery lifecycle services from which they can make more profits.

The B2U motivations of the major stakeholders are summarised in Figure 4.1. It can be seen from the data that the motivations described by the stakeholders are mostly regarding storage system cost reduction and additional revenues. However, Company B mentioned during the interview that "*if we choose EV charging we are actually helping automotive companies, which means they are more likely to do business with us*" (E-1). As a young start-up, a possible motivation for them to use Company A's second-life batteries might be that they want to connect to a big name in the automotive industry to help them enter the market and grow, although they did not show that directly. Interestingly, Company B also said: "*In our system, the battery cost is a small portion so second-life batteries don't really mean so much to us*" (E-1). This seems contradictory to their initial motivations but it also shows that the cost incentive might not be a sustainable motivation for developing second-life batteries.

B2U motivations of key actors		
Company A Benefit EV programme by generating additional revenues from second-life batteries	**Company B** Reduce system cost to build cost-effective energy storage to address EV charging problems	**Company C** Extend the economic life of battery packs to better profit from integrated lifecycle services

Figure 4.1 B2U motivations of key actors: Case study I

B2U benefits

According to Company A: "*The incentive of second-life battery has always been to benefit the EV programme. It is one thing to say I want to reuse those batteries and make some money on it; but it's another to say our EV programme has its own cost structure and I want to continue that to include this reuse activity. So when you look at the two pieces combining, the (B2U) programme's economics are improved*" (O-1-2). The data show that one of the envisioned

B2U benefits for Company A is additional revenues that will in turn provide benefits back to the EV programme, improving the cost structure and value of EVs. Company A is aware of the 'value' of second-life batteries not only in terms of economic value but also a broader social value: "*We can provide stationary battery systems using used batteries with reasonable price to increase the renewable generation. As a result, the electricity (for EV charging) will be cleaner and the EV value will be increased*" (O-1-2).

Since second-life batteries are currently much cheaper than new batteries, the direct benefit of using second-life batteries for Company B is reduced system cost. For Company C who stands between Company A and B, they profit from providing relevant B2U services to both sides. For the end-customers, Company B helps them "*avoid expensive and tedious charging infrastructure construction projects*" through the cost-effective and convenient charging services. In addition, as the CEO of Company B said, "*We are using night-time electricity rather than day-time electricity which saves money. And also we save customers in demand charges which could be huge in California*" (E-1). Therefore, through Company B's grid-smart charging system, the end-customers save in electricity bills through cutting the demand charges.

Company B also mentioned the benefits of their B2U business for the OEMs: "*We went to a market that will help them (Company A) sell the vehicles*" (E-1). By making EV charging much easier for the EV owners, it also contributes to quicker EV adoption. For new stakeholders like Company B and C, the cheap second-life batteries also bring in new business opportunities for cost-effective energy storage.

In general, investigations into B2U motivations (above section) show a single focus on economic profits from second-life batteries, for example, cost reduction for energy storage system providers or additional revenues to reduce EV capital cost either for consumers or automotive OEMs. However, findings from this case study show the existence and importance of other sources of potential benefits that exist for multiple B2U stakeholders. The envisioned benefits for various stakeholders in terms of economic, social and environmental aspects are summarised in Table 4.3.

Table 4.3 Envisioned stakeholder benefits of B2U: Case study I

Stakeholder	Envisioned B2U benefits
OEM	• Additional revenue streams • Increased value and cost structure of EVs • Quicker EV adoption
Energy company	• Reduced system cost for energy storage
Commercial buildings	• Reduced EV charging infrastructure cost for commercial buildings • Savings in electricity bills for commercial buildings
EV owners	• More convenient and cost-effective EV charging
Society & Environment	• Reduced cost and new business opportunities for energy storage • Renewable integration and cleaner electricity • Quicker EV adoption for a cleaner transportation system

B2U challenges

According to Company A: "*With the new battery price coming down, everything is making the life of second-life batteries difficult*" (O-1-2). Despite the fact that B2U has many environmental and social benefits, it would be difficult to find buyers of second-life batteries once they lose the cost advantage to new batteries. The data show that the most critical challenge for B2U is the competition from increasingly cheap new batteries.

Company B also mentioned several barriers to B2U: "*First of all, the price of new batteries is dropping significantly…Second, uncertainty of supplies...Regulation is a little bit of a factor because here in California we have a programme that subsidizes the cost of new batteries but not second-life batteries…I am working on the policy side in order to change that, so does Company A…The biggest barrier is the companies themselves, they've done a very poor work* *at standardization and transparency…In today's business world you need to be transparent – how much you have, how much it costs, what is the guarantee…*" (E-1).

The interview data suggest that in this case, the biggest challenge for the buyer of second-life batteries lies in the OEMs. There is a lack of standardization and transparency from the OEMs in terms of a steady and secure battery supply, a transparent pricing, standardized contracts and proper warranties. Those challenges might keep the buyers away from second-life batteries. As commented by the CEO of Company B, "*The new battery price is falling so quickly, we think in the long run our main suppliers would be new battery manufacturers… we will be earning a lower margin but we have longer longevity of the battery and we have performance guarantee etc*." (E-1). On the policy side, the lack of regulatory incentives for second-life batteries diminishes their cost advantages to new batteries.

Despite the potential benefits of B2U, there are still many challenges facing B2U players, especially automotive OEMs who are the initial asset owners. When asked about the issues with B2U technologies, the interviewees of Company A and D commented: "*From the technology side, we are ready…*" (BJV-1); "*Technically it is possible but economically it is uncertain…*" (O-1-2). The interviewee of Company B also said: "*There is not too much concern in terms of technology…the batteries all tend to be well-engineered…we have tested all the batteries and they are really safe and the chemistries are really good…even they are used batteries, they outperform on energy density (than some new batteries)*" (E-1). Unexpectedly, although most of the B2U literature is investigating the technical aspects of repurposing second life batteries, companies in this case study did not mention technical challenges. To some extent, this echoes the findings from the literature review in Chapter 2 that B2U is more a BM problem rather than a technical problem, and B2U researches are encouraged to shift from technical aspects to a wider business perspective. The B2U challenges identified in this case study are summarised in Figure 4.2.

- Competition from increasingly cheap new batteries
- Lack of standardisation and transparency from the OEMs:
    - ♦ Lack of a steady and secure battery supply
    - ♦ Lack of transparent battery pricing
    - ♦ Lack of standardized contracts
    - ♦ Lack of proper warranties
- Lack of regulatory incentives for second-life batteries

Figure 4.2 B2U challenges: Case study I

4.2.3 Business model description

This section presents the BM of second-life batteries developed by the major stakeholders in this case study. The BM is analysed and described using the analytical framework developed in Section 3.5. The activity system of second-life batteries in case study I is firstly illustrated in Figure 4.3. It presents how Company A develops second-life batteries with Company B and C through a series of activities and transactions. This explains, at the system level, how the major stakeholders interact to develop B2U business models that transform second-life batteries into the final solutions for the end-customers. The B2U business models of Company A, B and C are then respectively analysed in detail at the firm level.

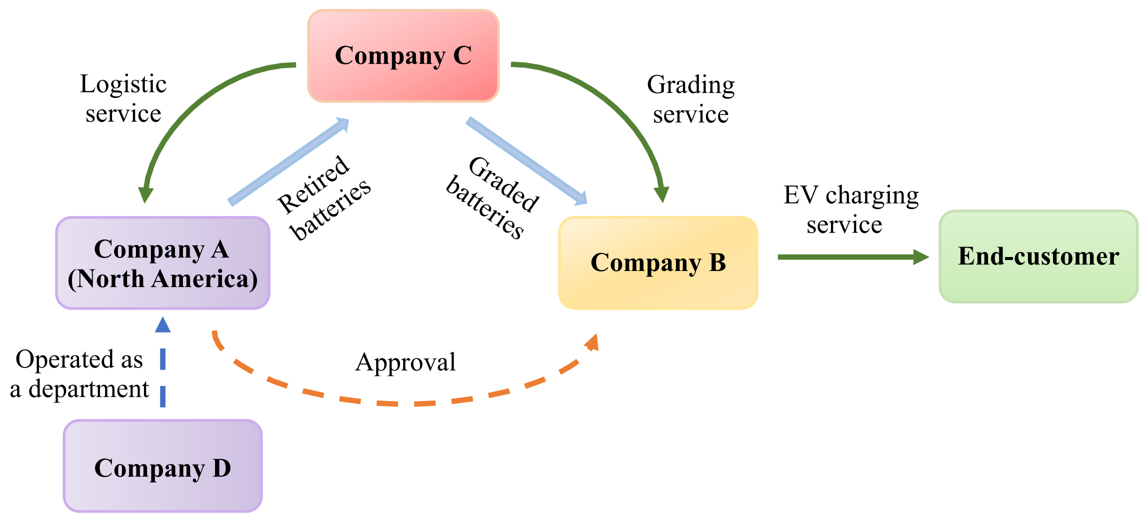

Figure 4.3 The activity system of second-life batteries: Case study I

Activity system of second-life batteries

In this case study, the activity system of second-life batteries includes the value creation activities conducted by the major stakeholders and the transactions in between that transform second-life batteries into the final solution for the end-customers. Company D is a joint venture set up by Company A in Japan with the specific purpose of developing B2U. Most of its activities worldwide are currently research and development rather than operating B2U businesses, and in North America this activity is currently conducted as a department within Company A (North America). As illustrated in Figure 4.3, Company B firstly needs to get approval from Company A and be labeled as "authorized users" of the second-life batteries at the start of their relationship. After a consensus has been reached, Company A sells used EV batteries at a very cheap price ($85/kWh as referred to by one of the interviewees) through the distributor Company C. What is worth noticing here is that there is no transaction between Company A and B and they do not sign a direct contract. The distribution and battery repurposing work is done by Company C, who provides relevant services to both sides in addition to buying and selling the batteries. Company C is responsible for collecting and disassembling the batteries, testing and grading them, and then selling the graded battery modules to Company B. Company C provides logistic services to Company A, helping the OEM collect used EV batteries from the dealers, transport the batteries and store them at their facilities. On the other side, Company C provides battery repurposing services to Company B, helping them with battery testing and grading. Company B then integrates the graded second-life batteries with power electronics and software to build their energy storage systems and provide mobile charging services to the end-customers. In this case, Company B does not get any warranty for the second-life batteries from either Company A or C because a warranty incurs extra costs. At the EOL of the second-life batteries, Company B is responsible for the recycling of the batteries.

Business model of Company A for B2U

For Company A, the BM is business to business (B2B) and the direct customer of second-life batteries is Company C. Its value proposition is the asset, the cheap used EV batteries. Company A's value creation in terms of B2U in this case study is very limited. They just collect the used batteries from EV owners through their car dealers and make them available for collection. They introduced the new stakeholder Company C who did most of the repurposing work. In this BM, Company A is merely the battery provider. They make profits by selling the used batteries at very cheap price, which contributes to their additional revenues. Besides, by selling the used batteries Company A also avoids the battery recycling cost. From the environmental perspective, postponing the battery recycling phase reduces the pollution, wastes and energy usage caused in the recycling process. In addition, repurposing a second-life as a cheap but still capable battery also helps reduce the system cost for energy storage, which helps create new business opportunities for companies like Company B and C. The key attributes of Company A's business model for B2U in this case study are summarised in Table 4.4.

Table 4.4 Summary of key B2U business model attributes for Company A: Case study I

BM attributes	Description
Customer value proposition	Cheap used batteries
Value creation	Battery collection from EV owners; introduction of new stakeholder for battery repurposing
Value network position	Second-life battery provider
Value capture	Additional revenues through selling the batteries; avoided battery recycling cost
Social & environmental value	Reduced pollution, wastes and energy usage for battery recycling; new business opportunities for energy storage

Business model of Company C for B2U

For Company C, their BM is to provide battery lifecycle management services to extend the lifetime of retired batteries. In this case, Company C's customers are the OEM and the energy storage company. Company C buys batteries from Company A, disassembles the battery packs, tests and grades them, and then sells graded battery modules to Company B. On top of that, Company C provides relevant services to both sides. Company C's value proposition for Company A is the logistic service: they collect used batteries for Company A from the car dealers, transport the batteries and store them at their own facilities. The value proposition for Company B is the delivery of tested and graded second-life batteries: they provide battery testing and grading services and sell the batteries at certain health to Company B. However, because Company A did not provide any data on the battery historical usage, the testing "*is not going to tell you the performance forward because that requires a lot more information from the OEM*." (L-1) The importance of battery data collection and sharing between stakeholders will be discussed in detail in Chapter 5.

The value creation of Company C includes logistics (battery collection, transportation and storage) and battery repurposing (battery testing and grading). Company C has the knowledge and expertise in battery grading which helps "*understand where the batteries come from, how good are they and what is the best usage profile*" (L-1). In this BM, Company C acts as the distributor, battery repurposer and battery lifecycle service provider that connects the OEM and the B2U system provider. Company C makes profits from providing relevant services to Company A and B: "*We offer many different services from the logistics to grading…we charge Company B* for *doing the repurposing job, and we also charge OEMs because we collect their batteries from the dealers. We make money from both sides*" (L-1). At the society level, extending the lifetime of the batteries for other applications through the battery lifecycle management services contributes to improved material efficiency, reduced resource exploitation and reduced environmental impacts. The key attributes of Company C's business model for B2U are summarised in Table 4.5.

Table 4.5 Summary of key business model attributes for Company C: Case study I

BM attributes	Description
Customer value proposition	For the OEM: logistic service For energy storage company: graded second-life batteries
Value creation	Logistics: battery collection, transportation and storage; Battery repurposing: battery testing and grading
Value network position	Distributor, battery repurposer and battery lifecycle service provider
Value capture	Profit from providing logistic service to the OEM and battery grading service to the energy company
Social & environmental value	Improved material efficiency, reduced resource exploitation and environmental impacts through extending the battery lifetime

Business model of Company B for B2U

The product developed by Company B is an intelligent mobile charging system built around second-life batteries. Company B designs the system to be able to move to the vehicles so that EV owners can access charging at any spot. The targeted customers are the corporations who have quite a few employees driving EVs. Those corporations are facing the problem of constructing expensive charging infrastructure at their companies. To solve this problem, Company B develops the intelligent mobile EV charging solution.

For Company B, the BM is to provide mobile EV charging as a service to the end-customers. Its customer value proposition is threefold. The first is the flexible and easily scalable EV charging service. As commented by the CEO and founder of Company B: "*For our customers, the most important part is that they have a much easier process to scale EV charging by taking away the need for construction projects*" (E-1). The mobile charging exempts the corporations from tedious and expensive charging infrastructure construction, which helps them avoid large upfront costs. The second value proposition is the savings in electricity costs especially the demand charges caused by peak-time EV charging: "*Because we are using night-time rather than day-time electricity which saves money…and also saves customers in demand charges which could be huge in California*" (E-1). The third value proposition is more convenience in EV charging for the end-users. The EV drivers can access charging at any parking lot without bothering to rotate in and out of the charging spot during work. Supported by Company B's software platform, the EV drivers can register their preferred time of charging and have EV charging on site.

Company B's value creation includes second-life battery system integration, product and charging service development that "*include everything the customers would need from attendant to hardware and software to insurance, literally everything they need to get it working*" (E-1). In this BM, Company B is the B2U system integrator and provider, as well as the EV charging service provider. Company B has many patents in hardware and software and they "*know how to work with second-life batteries*" (E-1). Company B built the system that "*can extend the lifetime of second-life batteries*" (E-1). Since they use cheap second-life batteries, Company B is able to reduce the system cost to provide cost-effective solutions for the end-customers. Company B makes profit from providing charging services to the end-customers, who pay for the service by month.

In Company B's business model, the mobile charging service also helps quicker EV adoption by addressing the charging problems. This is an additional value created for the OEM and the society as a whole in terms of building a cleaner transportation system. Besides, the intelligent energy management enables the batteries to store off-peak time electricity to charge the EVs during the day. This will benefit the grid through shifting the demand peak caused by simultaneous EV charging. The key BM attributes for Company B are summarised in Table 4.6.

Table 4.6 Summary of key business model attributes for Company B: Case study I

BM attributes	Description
Customer value proposition	Flexible, easily scalable and cost-effective EV charging; avoided large upfront cost for charging infrastructure; reduced demand charges and electricity bills;
Value creation	B2U system integration, product development and all-inclusive charging service
Value network position	B2U system integrator and provider; EV charging service provider
Value capture	Monthly payment for the charging service
Social & environmental value	Addressing EV charging problem that promotes EV adoption for a cleaner transportation system; Demand peak shifting for the grid

4.2.4 Review of the business model

In this case study, the OEM's business model for B2U is based on the traditional 'sell-and-disengage' logic. The application for second-life batteries is to provide mobile EV charging as a service. This is a niche market and the scale is small because the solution is provided by a very young start-up. The strength of the BM is that it requires little devotion and investment from the OEM. The risk is low and it is easy to execute. However, there are several limitations of this BM. Firstly, since the OEM is not involved in the final solution development, the value captured from second-life batteries is very small for the OEM: they stop profiting from B2U once they sell the ungraded batteries. Another limitation is that most of the risks regarding B2U are undertaken by Company B. Company A sells used batteries to Company B through a distributor and there is no direct transaction between the OEM and Company B: "*The contract is through the distributor (Company C) so it's not a direct contract*" (E-1). This has caused concerns for Company B because there is a lack of steady supply of batteries for them to scale up their business. As commented by the CEO and co-founder of Company B:

> "*I have no idea how many batteries Company A has and how much they can send each month… In order to scale up, we need to be 100% certain that Company A is going to keep providing us batteries, but I can't be sure about that, not today…*" (E-1).

Also, there is a lack of standardized contract between the OEM and Company B: "*We don't have a contract with Company A today. And it adds on uncertainties for our business*" (E-1). In addition, because Company B does not get any warranty from the OEM or Company C, they bear all the risks in terms of battery performance and quality: "*Currently we don't have any warranty from Company A but we are negotiating…I do expect the warranty…if we can't get a warranty then we will stop using Company A's second-life batteries*" (E-1).

These limitations have put the BM under risk. Company B is willing to bear the risks regarding B2U because currently second-life batteries are a lot cheaper than new batteries. But with the cost advantage of second-life batteries vanishing, this BM is not sustainable as companies like Company B could easily abandon second-life batteries and turn to new batteries. As commented by the CEO of Company B: "*If the OEMs are too difficult to work with, then we will simply move to other suppliers. We are not tied to second-life* *batteries…and because battery price is falling so quickly, we think in the long run our main suppliers would be new battery manufacturers*" (E-1).

From the OEM's perspective, this BM is one of their experiments with B2U in applications which "*is of lower priority*" for them. As commented by the president of Company D: "*It is not a perfect reuse business but it is commercialized… from our perspective we just sell the used batteries to them. Our involvement is small and return is small too… In the future, we will probably just sell the batteries to them or deeply collaborate, but we are not sure yet*" (BJV-1).

However, thanks to Company B's service-based model, the value of second-life batteries is not diminished for the end-customers because the end-customers do not care what kind of battery it is – they only care what kind of charging service they get. As captured from the following quotes from Company B: "*Our customers don't care whether you use Company A's old batteries, as long as it does what they tell us to do*" (E-1). The perceived risks in terms of the quality and performance of second-life batteries are not held by the end-customers. With the service-based BM, the 'inferiority' of second-life batteries as 'used products' is overcome because end-customers get what they want – the charging service. Nonetheless, with the cost advantage of second-life batteries diminishing, the OEM's business model is not sustainable because customers like Company B could easily switch to other battery suppliers.

In summary, the OEM's B2U business model in this case study is based on the traditional product selling model which has brought commercial simplicity but has also caused substantial challenges. For the OEM, the risk is low and the devotion required is small, but the consequence of that is low rewards from B2U. Their motivation for B2U is all about cost and additional revenues instead of trying to maximise the value of second-life batteries. They get paid by selling the battery asset at a very cheap price whereas the potential value of second-life batteries is neglected. There are more benefits available that they are not accessing, but the 'sell-and-disengage' logic of the BM prevents them from capturing the potential value from those batteries.

B2U is still at its emerging stage, with stakeholders exploring and experimenting with different BMs to create and capture value from second-life batteries. This case study suggests that the traditional 'sell-and-disengage' logic might no longer be suitable for B2U and companies might shift to more service-based BMs. As commented by the president of Company D: "*Battery reuse should be service-based, not selling the batteries – that's why from our point of view, it (the business with Company B) is not a 100% reuse business…*" (BJV-1).

4.3 Case study II

4.3.1 Introduction to Case II

This case study presents another B2U business model of Company A (North America). The key stakeholders involved are the OEM and an energy storage company (Company E). Company E is the major partner of Company A in this BM, who develops and delivers the final solution for the end-customers. Connected through Company A, the researcher also visited Company E and conducted in-depth interviews with the most relevant people at the company. Company A has already been introduced in Section 4.2.1.

Company E is an energy storage company in California. Company E focuses on providing commercial energy storage solutions to reduce demand charges and save energy costs for businesses and institutions. Through a combination of predictive software and risk-free financed battery hardware, Company E provides their customers with the solution to save on energy bills with no upfront cost. The core of Company E's business is that they own and operate the energy storage system and share the energy savings with the customers. Company A and E announced a partnership in 2015 with the aim to enable commercial use of second-life EV batteries as part of Company E's energy storage solutions.

The reason for choosing this case study is that Company E has been working closely with Company A on B2U for years and develops the final solutions to commercialize second-life batteries. This case study is to present how Company A collaborates with Company E to deploy B2U in commercial and industrial applications and create value from second-life batteries. Interviews were conducted with the manager of battery business unit and the general manager of EV operations of Company A (Japan), the general manager of Company A (North America) and the COO of Company E. The detailed list of interviews can be found in Table 4.7.

Table 4.7 List of interviews: Case study II

Company	Stakeholder role	Region	Interviewees' position	Reference code	Time (mins)
A	OEM	Japan	Manager, battery business unit; General manager, EV operations	O-1-1	125
		North America	General manager	O-1-2	127
E	Energy storage	California	COO	E-2	63

4.3.2 B2U motivations, benefits and challenges

B2U motivations

The B2U motivations for Company A have been discussed in Section 4.2.2. According to Company E: "*The reason we are looking at second-life batteries is that they will be cheaper than the brand-new batteries...In some cases we actually have customers that just want to use second-life batteries and help with reusing something with green effect.... More of the non-profit companies like the idea of reusing second-life batteries*" (E-2). The data show that the main B2U motivation for Company E is the cheaper price of second-life batteries compared with new batteries. B2U enables Company E to reduce system cost so that they have access to more business cases to expand their customer base or provide more valuable offerings to their current customers. Besides, they want to reach customers that would like to promote sustainability through using second-life batteries. Interestingly, Company E also perceives the social and environmental value of second-life batteries as one of their motivations to develop B2U. The B2U motivations for the major stakeholders in this case study are summarised in Figure 4.4.

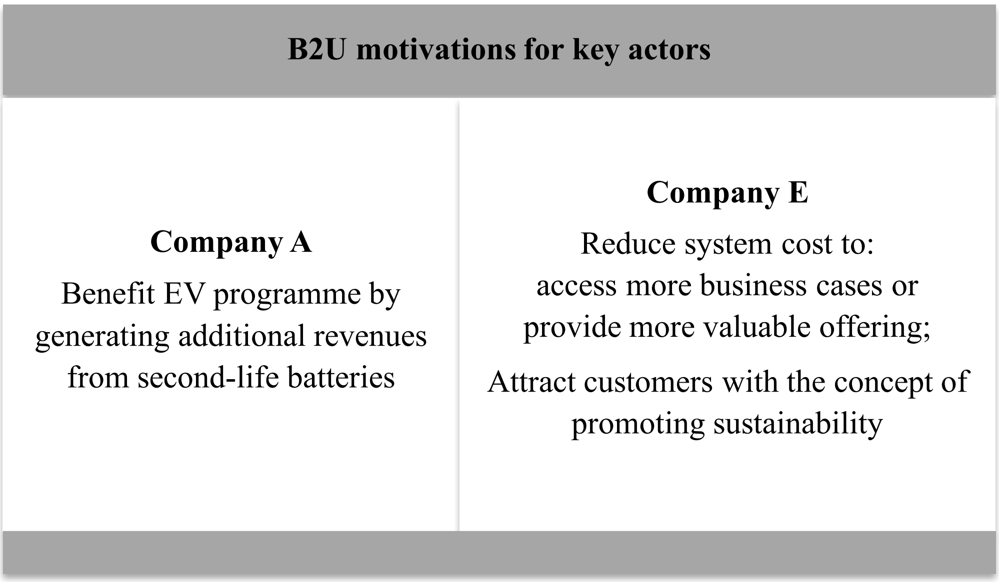

Figure 4.4 B2U motivations for key actors: Case study II

B2U benefits

The envisioned benefits of B2U described by Company A have been discussed in Section 4.2.2. The COO of Company E described B2U as ‘*an excellent win for everybody’*:

> “*It is a lower cost resource for us, which allows us to reach more customers or just save more money for customers where we install it… It is better for the utility, for rate payers, for customers, for battery reuse companies, for companies like us…It is a win-win-win-win-win business*” (E-2).

In this case study, the benefits of B2U for Company E include reduced system cost and expanded customer base. The end-users of second-life battery systems benefit from more service options and a higher savings in electricity bills because Company E promises higher saving portions if customers choose second-life battery systems (details presented in Section 4.3.3). At the society level, "*when electricity peaks are brought down on the demand side, utilities could run more efficiently without spending more expenses for the infrastructure upgrade…*" (E-2). Therefore, the potential social and environmental benefits include more efficient running of power plants and deferral/avoidance of grid infrastructure upgrade, and thus lower energy rates for consumers. It can be seen from the data that while the stakeholders are mainly motivated by the economic benefits of cost reduction and additional revenues from B2U, multiple sources of benefits exist for various stakeholders. The envisioned stakeholder benefits of B2U in this case study are summarised in Table 4.8.

Table 4.8 Envisioned stakeholder benefits of B2U: Case study II

Stakeholder	Envisioned B2U benefits
OEM	• Additional revenue streams • Increased value and cost structure of EVs • Quicker EV adoption
Energy storage company	• Reduced system cost for energy storage • Expanded customer base
Electricity consumers	• More service options and higher savings in electricity bills for commercial and industrial buildings
Society & Environment	• Demand peak reduction and more efficient operation of utilities • Avoidance or deferral of grid infrastructure upgrade • Lower energy cost for rate-payers

B2U challenges

When it comes to the challenges of B2U, the COO of Company E commented: "*There is not a market established yet. They (Company A) know they have to be cheaper than new batteries, which is really challenging because the price of new batteries is dropping quickly…*" (E-2) The competition from new batteries is also regarded as the major challenge by Company A (discussed in Section 4.2.2). The data indicate that with new batteries cost decreasing rapidly, it will be increasingly difficult for second-life batteries to compete in the market.

4.3.3 Business model description

This section presents the B2U business model developed by the major stakeholders in this case study: Company A (North America) and Company E. The BM is analysed using the analytical framework developed in Section 3.5. The activity system of second-life batteries is first illustrated in Figure 4.5 to present how Company A develops second-life batteries with Company E through a series of activities and transactions that transform second-life batteries into the final solutions for the end-customers. The BMs of Company A and E for B2U are then analysed and described at the firm level respectively.

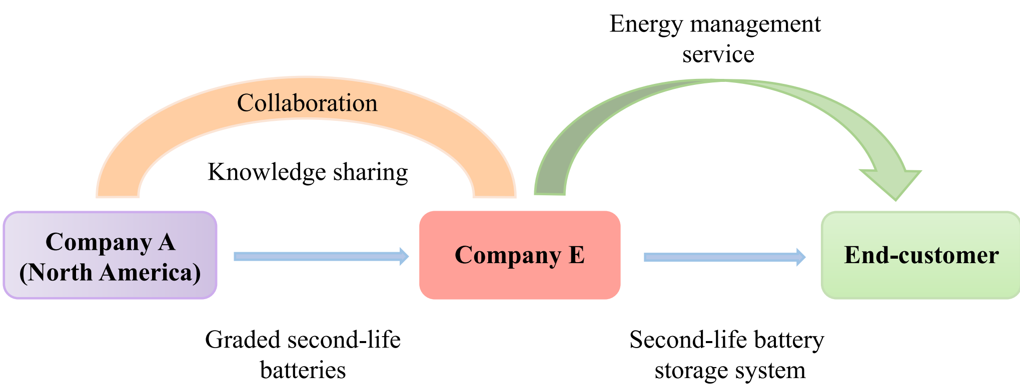

Figure 4.5 The activity system of second-life batteries: Case study II

Activity system of second-life batteries

Although the partnership between Company A and E was not announced until 2015, the two companies had started testing and development activities 2 years earlier. Both parties have made efforts in testing, construction, evaluation, and optimization of second-life batteries through this collaboration. Company A collects second-life batteries from their car dealers, tests and grades them based on the historical battery usage data collected from their Global Data Centre (GDC). As shown in Figure 4.5, Company A sells graded second-life batteries to

Company E, but apart from selling the asset, Company A also shares their knowledge and expertise to help make the batteries fit into Company E's standard systems and deliver the level of performance that Company E requires through collaborative testing and evaluation: "*We are working towards being able to help Company E be able to use both new batteries and used batteries from us and still deliver the same level of power or capacity*" (O-1-2).

To better evaluate the battery performance in energy storage applications, Company E shares the degradation curves of their battery usage profile with Company A. Based on that usage profile combined with the battery historical usage data from their GDC, Company A is able to predict the performance of second-life batteries under the specific usage profiles. For second-life batteries, Company A provides a 10-year performance guarantee for Company E and if the battery performs under a certain agreed level, they will change the batteries for Company E for free.

Company E develops the battery storage system that integrates the second-life batteries from Company A. As shown in Figure 4.5, Company E provides energy management services to the end-customers instead of selling the storage devices. They install the system at the customers' sites for free and provide energy management services to cut the electricity peaks and reduce the demand charges for the end-customers. Company E signs a 10-year contract with the end-customers, and after that 10 years, they will take back those batteries and send them to Company A, who is responsible for recycling the batteries.

Business model of Company A for B2U

For Company A, the BM is business to business (B2B) and their direct customer is Company E. Its value proposition is the cheap but still capable second-life batteries that fit into Company E's standard battery storage system. The value proposition is mainly the selling of asset, but it also includes the concept of service where Company A tries to "*help Company E be able to use used batteries from Company A that still deliver the same level of power or capacity (as new batteries)*" (O-1-2).

The value creation of Company A includes: collecting and repurposing used battery packs, testing and grading the batteries, and evaluating second-life battery system in collaboration with Company E to make sure that the batteries meet their requirements. In this BM, Company A is the second-life battery provider and repurposer, as well as the knowledge partner for Company E. Company A has the best knowledge and expertise in their EV batteries: they know "*all the chemistry and engineering of the batteries and how they behave*" (O-1-2). And supported by their GDC where they can trace the historical battery usage data, Company A is able to evaluate the state of health (SOH) of the batteries. However, Company A *"knows all about the car battery, but not so much about batteries being used not in a car*" (O-1-2). Apart from the SOH, the remaining lifetime and performance of the batteries in energy storage also depend on how they will be used for their second-life applications, and that's why Company A did B2U in collaboration with Company E instead of on their own. And because Company E has their standard systems (where the second-life battery pack is not the right size), Company A needs to jointly work with Company E to optimize the battery configuration for the battery storage system. Company A prices second-life batteries with Company E and makes profits from the sales of the battery asset.

Through this BM, Company A also creates value for the society and environment. By repurposing a second-life for the retired batteries instead of recycling them, the pollution, wastes and energy consumption related to the recycling process are reduced. Besides, second-life batteries provide a cost-effective solution for energy storage which helps the promotion of battery storage for energy-related services. At the society level, extending the battery life for other applications improves the material efficiency and reduces resource exploitation and environmental impacts. The business model of Company A for B2U in this case study is summarised in Table 4.9.

Table 4.9 Summary of key B2U business model attributes for Company A: Case study II

BM attributes	Description
Customer value proposition	Cheap but capable second-life batteries that fit into Company E's energy storage system
Value creation	Battery collection and repurposing; collaborative system testing and evaluation with Company E
Value network position	Second-life battery supplier and battery knowledge partner
Value capture	Get paid by selling customized second-life batteries
Social & environmental value	Reduced pollution, wastes and energy usage for battery recycling; promotion of energy storage; improved material efficiency, reduced resource exploitation and environmental impacts through extending the battery lifetime promotion of cost-effective battery storage for energy services

Business model of Company E for B2U

For Company E, the BM is business-to-customer (B2C). Their targeted customers are commercial and industrial buildings or institutions such as schools. In California, up to 50% of the electricity bill for commercial and industrial buildings could be composed of demand charges (as high as $48/kW in San Diego). Company E's value proposition is to reduce the electricity bills for the end-customers through providing energy services to cut the demand peak. In this case, Company E jointly tests and evaluates the second-life battery performance with Company A: "*We spent 18 months testing the product with them (Company A), doing R&D, integration, communication, testing ... when we put it in the field, it took us 18 months*" (U-2). Company E designs and engineers the system, buys key components from their partners and integrates the system through contract manufacturers. Company E bears the upfront cost of the system and owns the asset. They install the system at the customers' sites for free and operate the system for the customers to level out their energy usage. For buildings with photovoltaic (PV) panels on their roofs or with EV drivers, the storage system could also be used for various energy services e.g. energy arbitrage, solar firming and EV charging buffer to optimize the electricity tariff for the customers.

In this BM, Company E is both the B2U system integrator and energy service provider. Instead of selling the asset, Company E makes profits from sharing the savings in energy bills with their customers. And in this case of B2U, they offer their customers higher sharing of energy bill savings if they choose B2U systems instead of new battery systems.

Through this BM, Company E also creates value for the society and environment. By reducing the electricity peak at the demand side, the energy services provided by Company E help utilities balance the grid and run the power plants more efficiently, which contributes to a more stable power system and reduced environmental impacts. In the medium to long term, managing the demand-side energy consumption could help defer or even avoid grid infrastructure upgrade and the need to build new peaking plants. In addition, installing energy storage at the demand-side could also help with more efficient renewable integration which contributes to a cleaner electricity mix. The key B2U business model attributes for Company E is summarised in Table 4.10.

Table 4.10 Summary of key B2U business model attributes for Company E: Case study II

BM attributes	Description
Customer value proposition	Reduction in electricity bills through cutting the demand charges
Value creation	Collaborative battery testing and evaluation with Company A; B2U system integration through contract manufactures; system development, installation and operation at customers' sites
Value network position	B2U system integrator and energy service provider
Value capture	Share the savings in electricity bills with customers
Social & environmental value	Grid demand balancing and more efficient operation of power plants; defer/avoid grid upgrade and new power plants construction; more efficient integration of renewables; reduced environmental footprint

4.3.4 Review of the business model

The application of second-life batteries in this case is behind-the-meter energy management services for industrial and commercial buildings. For the OEM, the BM is mainly based on the traditional ‘sell-and-disengage’ logic. Different from the previous case, however, the OEM’s business model in this case also involves the concept of service where the customer’s demands were taken into account. The OEM not only sells the battery asset but also collaborates with their customer (Company E in this case) to enable the second-life batteries to meet their customer’s requirements and fit into their standard system. This BM requires complementary resources and collaborative activities from Company A and E in terms of the battery system design, big data of the battery quality and the battery performance evaluation in energy storage.

In this case, the value of second-life batteries for the end-customers is not diminished because of Company E's service-based BM: "*Customers won't care that it's used batteries because they can get more savings. In our case, it becomes our risk where we own the asset*" (E-2). The end-customers do not have a negative opinion towards second-life batteries in that they do not pay upfront cost for the batteries and in the meanwhile they get more savings: they just provide the space, have their electricity usage profile optimized and share on the energy savings with Company E. The perceived risks of second-life batteries, for example, the uncertainty in remaining capacity, lifetime and degradation, are taken away from the end-customers: "*We are willing to take the risk because Company A has well-performed technology behind it and they guarantee that so we are not too concerned…*" (E-2). Through the warranty offered by Company A, the risks are shared by Company A and E.

However, Company A is not involved in the final solution development for the end-customers where the value of second-life batteries is ultimately realized. That is, Company A does not benefit from the value of the batteries in terms of the energy services provided by the batteries during their second use. And the risk of this BM is that it is vulnerable to competition from increasingly cheaper new batteries. Also, this BM is likely to change in the future, with the accumulation of knowledge and experience in second-life batteries being used in energy storage applications. For example, Company A might provide Company E with "plug-and-play" standard second-life batteries just like new batteries which do not require collaborative testing anymore.

This BM is also influenced by several external forces. First of all, there is a good market demand for battery storage in California, especially the demand to level out renewables which become increasingly integrated. Second, the regulators in California are very supportive of renewables and energy storage. As the COO of Company E said, "*There is a great opportunity in California for battery storage based on the renewable standards … there are going to have a lot of state-level mandates for battery storage to be implemented*" (E-2). Thirdly, people in California are generally more comfortable with the concept of reuse which makes it easier for B2U, as one of the interviewees commented: "*People don't like used things, but in California the notion of reuse and recycling is brought to be a positive thing. I don't think it's going to be* *a negative opinion from the customer base about it, they will think it's really interesting*" (E-2).

In summary, the OEM's B2U business model in this case study is mainly based on the traditional product selling model. However, the concept of service is also included where they collaborate with their customer (Company E) in the battery performance evaluation and system design. Apart from selling the battery asset, they also share data and knowledge on the battery side to help Company B better design the system for second-life batteries. The risks concerning second-life batteries are not held by the end-customers but are shared by the OEM and Company E. Instead of selling the battery system, Company E owns and operates the battery asset, and provides energy services to end-customers to help them save in energy costs. Due to Company B' service-based BM, the 'inferiority' of second-life batteries as 'used product' is not perceived by the end-customers and thus the value of the batteries is not impaired. However, the OEM is not involved in the final battery solution development which prevents them from profiting from the value of the energy services provided by the batteries.

4.4 Case study III

4.4.1 Introduction to Case III

In this case study, the B2U business model involves two major stakeholders: the OEM and a power management company (Company F). The OEM in focus in this case study is Company A (Europe). Company F is the major partner of Company A in this case, who jointly develops the system and delivers the final solutions to the end-customers. Connected through Company A, the author also conducted in-depth interviews with the most relevant people at Company F. Company A has already been introduced in Section 4.2.1.

Company F is a multinational power management company with 2015 sales of $20.9 billion headquartered in Dublin, Ireland. Company F's business comprises electrical and industrial sectors, and B2U is a part of the electrical sector's businesses. The electrical sector of

Company F is a global leader in power distribution, power quality as well as power control products and services. The collaborative development between Company A and F enables the resource and expertise integration of the two parties to develop the second-life battery solution for the end-customers. Their first product started pre-orders in UK, Norway and Germany from November 2016 and the two companies expect to sell more than 100,000 units within the next five years.

The reason for choosing this case study is that Company A jointly develops the final B2U solutions with Company F and their product is the first of its kind in the market using second-life batteries. This case study presents how Company A collaborates with Company F to create and capture value from second-life batteries. In-depth interviews were conducted with the general manager of Zero Emission Strategy and the manager of vehicle-to-grid (V2G) and Stationary Storage of Company A (Europe), as well as the vice president of EMEA (Europe, Middle East and Africa) Marketing at Company F. The detailed list of interviews in this case study can be found in Table 4.11.

Table 4.11 List of interviews: Case study III

Company	Stakeholder role	Region	Interviewees' position	Reference code	Time (mins)
A	OEM	Europe	General Manager, Zero Emission Strategy;	O-1-3	121
			Manager, V2G and Stationary Storage	O-1-3	54
F	Power/energy management	Europe	Vice president of EMEA Marketing	E-3	50

4.4.2 B2U purposes, benefits and challenges

B2U motivations

When it comes to why B2U, the manager of V2G and stationary storage at Company A (Europe) said: "*The first is there is business there – this is the main motivation. We have a battery which is still useful and there is need for energy storage. Why to recycle something that is still useful? Second, it is always better to reuse than to recycle. From the economic side, recycling means cost but to reuse there is a chance to have additional businesses and revenues. And to reuse is more environmentally friendly*" (O-1-3). The data show that for Company A (Europe), the main motivations of B2U include: a) to utilize the still capable second-life batteries to fulfil the market needs for energy storage; b) to transform the recycling cost into revenue opportunities; and (c) to provide a more environmental friendly option for EV battery EOL strategies.

For Company F, the main motivation of B2U is captured from the following quotes: "O*bviously there is a value there and they allow us to fulfill certain specific market demands very cost-effectively*" (E-3). The data show that the B2U motivation for Company F is that they see a positive economic value in second-life batteries which allows them to fulfill certain market demands cost-effectively. As said by the interviewee of Company F: "*I don't' see any reason to throw away something that clearly has an economic value because it can be used to deliver a service that people can take for...it is foolish to throw away something that is still valuable…*" (E-3). In addition, although not directly mentioned as the motivation, the interviewee of Company F said: "*Company A is probably a better brand enabling us to reach more consumers and more places…*" (E-3). It can be seen from the data that the brand of the famous OEM could be one of the motivations for Company E to develop B2U with Company A. Interestingly, in this case both companies are considering the value of second-life batteries in the energy market as one of their motivations for B2U. Company A also considers the environmental impacts of the batteries and regard B2U as a more environmentally friendly option than recycling. The motivations of the major stakeholders in this case study to develop B2U are summarised in Figure 4.6.

B2U motivations for key actors	
Company A Utilize capable second-life batteries to fulfil the needs for energy storage; Transform the recycling cost into revenue opportunities; Provide a more environmentally-friendly option for EV battery EOL strategies	**Company F** Utilise the positive economic value in second-life batteries to fulfill certain market demands cost-effectively; Use the brand of the OEM to reach more customers

Figure 4.6 B2U motivations for key actors: Case study III

B2U benefits

The envisioned benefits of B2U are, as described by the interviewee of Company F: "*In general if you want to make profitable storage system with new batteries, you have to combine multiple value streams. With second-life batteries, you can start making profit even if you only have one value stream, it allows you to lower the cost of the system*" (E-3). The data indicate that for Company F, the benefit of B2U is the economic value from second-life batteries which enables them to lower the system cost. For the end-customers, the cheaper second-life battery system allows them to profit at a lower threshold which makes the storage system more economical. For Company A, the benefits are additional revenue streams and increased EV value, which will in turn make EVs more affordable. As described by the interviewee of Company F: "*We give a value to those second-life batteries which would be otherwise thrown away, so it makes EVs more affordable*" (E-3). The envisioned benefits of B2U for various stakeholders are summarised in Table 4.12.

Table 4.12 Envisioned stakeholder benefits of B2U: Case study III

Stakeholder	**Envisioned B2U benefits**
OEM	• Additional revenue streams • Increased EV value • Making EVs more affordable
Energy/ Power company	• Reduced system cost for more economical energy storage system • Expanded customer base
Electricity consumers	• Reduced system cost • Lower threshold to make a profit from the system
Society & Environment	• Reduced environmental impact from the batteries • Renewable integration and cleaner electricity

B2U challenges

One of the B2U challenges described by Company A is the competition from new batteries: "*Battery is becoming cheaper and not only cheaper but also with better capabilities. The cost per kWh is dropping significantly…*" (O-1-3). In addition, one of the interviewees of Company A said: "*Our really concern is that second-life battery return will come later than expected…*" (O-1-3). It can be seen from the data that Company A is concerned about the return flow of second-life batteries in the near future because of battery technology improvement and thus, the expected longer lifetime of the batteries in EVs. Company A is now providing both the second-life and new battery options. As one of the interviewees said, "*We are now using not only second-life but also new batteries to enter the market. If we don't have enough second-life batteries, we will build new batteries as a backup*" (O-1-3).

According to Company F, there are three major challenges for B2U. As described by the interviewee of Company F: "*One challenge with second-life batteries is that almost by definition, it is impossible to be sure of how long it will last… I know that Company A has done some aging testing but it is not exactly the same thing*" (E-3). However, one of the interviewees of Company A said: "*We know that our batteries behave in this or that ways depending on the final usage…whether it is intensive in energy or power, how many cycles they have in a day or a week – it depends. We provide warranty to Company F, and the warranty to the end-customer is provided by them not us*" (O-1-3). It can be seen from the data that there might be information asymmetry between Company A and F: Company A thinks they know well about how the batteries behave under certain usage profiles while Company F is concerned about the uncertainty lies in the battery performance in second use applications, although Company A provides the warranty.

On the customer's side, one of the B2U challenges is people's bias towards second-life batteries as 'used product'. As the interviewee of Company F said: "*Another challenge is that people often have low price expectation for second-life batteries, so we have to tell them the value of the system, not necessarily the system cost, but on the value – you are going to make such a return on investment*" (E-3). In terms of regulation, Company F thinks that the third challenge for B2U is that the "*regulation in grid ancillary services market is not transparent and open now*", which makes it hard to determine "*what are the conditions under which user is buying and selling the power to the grid operators*" (E-3). The B2U challenges described by the major stakeholders in this case study are summarised in Figure 4.7.

- Competition from increasingly cheap new batteries
- Uncertain return flow of second-life batteries
- Uncertain performance of second-life batteries
- Customers' bias towards second-life batteries as 'used product'
- Lack of transparent and open regulation in grid ancillary service market

Figure 4.7 B2U challenges: Case study III

4.4.3 Business model description

This section presents the BM for second-life batteries developed by the major stakeholders in this case study: the OEM and the power management company. The BM is analysed using the analytical framework developed in Section 3.5. The activity system of second-life batteries is firstly illustrated in Figure 4.8 which presents how Company A jointly repurposed a second life for the retired EV batteries with Company F through a series of activities and transactions. The B2U business models of the two companies in this case study are then analysed at the firm level respectively.

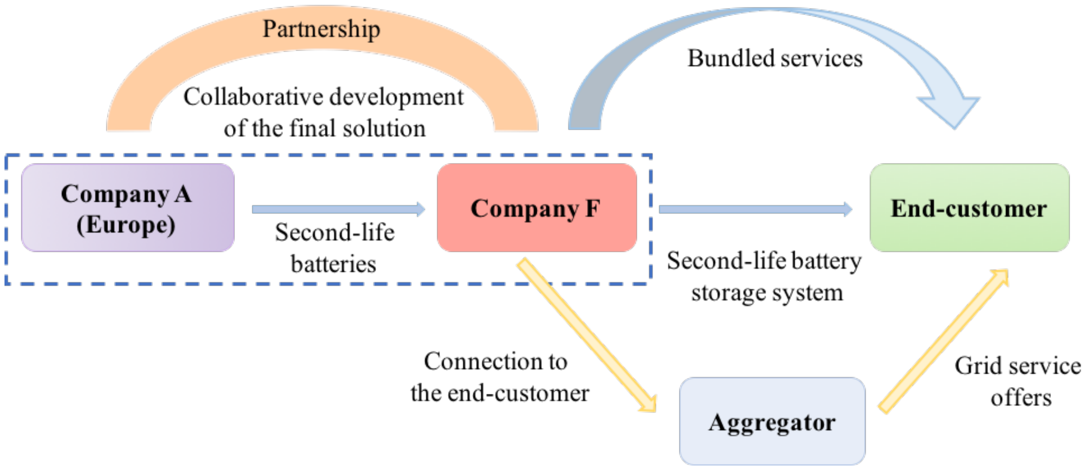

Figure 4.8 The activity system of second-life batteries: Case study III

Activity system of second-life batteries

As illustrated in Figure 4.8, Company A and F jointly developed the final second-life battery solution for the end-customers through a collaborative development. Company A collects the batteries, disassembles them into modules, tests the state of health (SOH) of each module and grades them, ensuring the performance (over 70% remaining capacity) and the health of each battery module before selling them to Company F. Company F is then responsible for integrating the second-life battery modules with power electronics and software to build the storage system. In this case, Company A sells graded battery modules to Company F, but beyond that, the two companies integrate their strengths and resources into developing the final solution for the end-customers. As described by Company A: "*We share objectives, knowledge and expertise*" (O-1-3). They develop things together and they also study the market and go together to the market.

In terms of delivering the final solution to the end-customers, Company F sells the storage systems through their traditional distribution channels. Apart from that, Company A also help sell the systems through their car dealers. They are also planning to lease the product using their financial arms. Company F also provides bundled services to the end-customers to help create higher value for the asset: they train and certify the installers to help customers get the system installed safely through their installation network; they also provide their customers with maintenance services that go with the offer. More importantly, Company F sees the value of the battery in grid-rated applications so they also help connect the end-customers with aggregators who provide grid-related service offers to the end-customers. Company F provides a ten-year warranty on the system for the end-customers. And when the batteries could be used anymore, Company F will take back those battery modules and send them to Company A for recycling.

Business model of Company A (Europe) for B2U

For Company A (Europe), the BM in this case study is selling graded and validated second-life battery modules, as well as collaboratively designing, developing and marketing the second-life battery solution with the expert power management company (Company F). The direct customer of second-life batteries is Company F but the end-customer of the product is residential consumers. Part of the value proposition is the validated second-life battery modules for residential storage, but more importantly, it is the sharing of knowledge and expertise on the batteries that goes into the collaborative development of the final solutions. As described by Company A,

> "*We have our know-how and we know that our battery will behave in this or that ways… we follow our project together, sharing curves and how this could be working…we plan together with Company F – how we develop the product, how we design it and how put it into the market*" (O-1-3).

The value creation of Company A (Europe) includes: collecting used battery packs, dissembling them into modules, testing and grading each module based on their SOH data to ensure that the batteries have over 70% remaining life. In this case, the OEM shares and utilizes their battery quality data in the final solution development. As said by one of the interviewees of Company A: "*We use the SOH data to design and develop the solutions*" (O-1-2). Company A jointly develops the battery management system (BMS) and inverters with Company F for the storage system. In addition, they collaboratively design, develop and market the final solutions together with Company F. In this B2U business model, Company A (Europe) is both the second-life battery supplier and the key knowledge partner for Company F. As described by Company A (Europe): "*We are their (Company F) supplier in terms of selling them modules but we are also partners. We go together and discuss together what answers we have to give depending on the request from customers…*" (O-1-3).

Company A (Europe) makes profit from selling second-life battery modules to Company F. Besides, since they are involved in the final product development, Company A also benefits from the final product offering side. For example, Company A sells the system through their car dealers. They are also planning to lease the product through the financing arm of Alliance A (Company A is a part of the alliance), so Company A will benefit from the leasing offer. The value created for the society and environment through this BM is presented in Table 4.13.

The B2U strategy for Company A is to disassemble the battery pack, test and grade the modules, resemble the modules with similar performance and add a new BMS to form a new battery pack. This adds to additional cost than just to use the whole battery pack as it is without opening it and reconfiguring. But according to Company A (Europe), "*Our calculation says that it's better to use modules than packs, because you've got longer second life than to use the pack*" (O-1-3). The different B2U strategies will be discussed in detail in Chapter 5. The key attributes of the BM of Company A (Europe) for B2U are summarised in Table 4.13.

Table 4.13 Summary of key B2U business model attributes for Company A (Europe): Case study III

BM attributes	Description
Customer value proposition	Cheap but still capable second-life battery modules for residential storage; sharing of knowledge and expertise on the batteries that goes into the final solution development
Value creation	Battery pack collection and dissembling into modules; testing and grading each module to ensure the battery performance and SOH; collaboratively developing the BMS and inverters with Company F; collaboratively designing and developing the system with Company F; marketing the final solution together with Company F
Value network position	Second-life battery supplier and key battery knowledge partner
Value capture	Revenue from selling second-life battery modules; benefit from the leasing offer of the final product
Social & environmental value	Reduced pollution, wastes and energy usage for battery recycling; promotion of energy storage; improved material efficiency, reduced resource exploitation and environmental impacts through extending the battery lifetime; promotion of cost-effective and more environmentally batteries for energy storage

Business model of Company F for B2U

For Company F, the BM in this case study is collaboratively designing and developing the second-life battery solution with Company A and delivering the final product and relevant services to the end-customers. Their targeted customers in this case study are residential customers, especially those with PVs on their roofs. Its value proposition is the cost-effective battery storage system with bundled services which enables the end-customers to increase PV self-consumption, reduce electricity bills, improve electricity security and participate in grid-related services to generate additional revenues. As described by Company F: "*The most important thing is to understand what the customer is looking for…and try to bundle the installation service, maintenance service, financial service, aggregation service in a way that is going to make his life easy*" (E-3).

Company F creates value for the end-customers through a series of value creation activities. They buy the graded and validated second-life battery modules from Company A, build the system integrating the OEM's knowledge and expertise on batteries with theirs in power electronics and the electrical grid, jointly develops the BMS and inverters to improve the system performance together with Company A, trains and certifies the installers and connects the end-customers with electricity aggregators. In this BM, Company F is the B2U system integrator, the product developer and service provider. They sell the final product to the end-customers through their traditional electrical sales channels, but apart from that they also sell through the Company A's car dealers as well as Alliance A who will be leasing the product. Company F makes profit from selling the battery storage product as well as the relevant services that go with the offering. Besides, by putting the aggregators in contact with the end-customers, Company F also benefit from sharing the aggregator's revenue.

Through this BM, Company F also creates value for the society and environment. As described by the interviewee of Company F, "*We think the battery can be a part of a much bigger grid and have a lot of services and interactions with the grid… We don't think PV and batteries as a way to disconnect from the grid, we think it as a way to improve the grid…*" (E-3). The data show that second-life batteries provide a cost-effective and more environmentally friendly solution to energy storage, which will help with more efficient renewable integration and operation of the grid. The key B2U business model attributes for Company F is summarised in Table 4.14.

Table 4.14 Summary of key B2U business model attributes for Company F: Case study III

BM attributes	Description
Customer value proposition	Cost-effective and safe battery storage system with bundled services; increased PV self-consumption, reduced electricity bills, improved electricity security and additional revenues from being able to participate in grid-related services through the storage system
Value creation	B2U system integration and collaborative product development; collaborative system performance optimization with Company A trains and certifies the installers; connects the end-customers with electricity aggregators
Value network position	B2U system integrator, product developer and service provider
Value capture	Sales of the product and bundled services; share of revenues from the aggregators

4.4.4 Review of the business model

In this case study, the application of second-life batteries is residential energy storage. Unlike the previous BMs, the OEM in this case is involved in the final solution development which allows them to create and also capture more value from second-life batteries. Instead of just selling the battery asset to get additional revenues, Company A is trying to create value for second-life batteries by integrating complementary resources and knowledge through a collaborative development with Company F. In addition, they also utilize the power of their brand to increase the value of the product. The two companies have been progressing well through the partnership and they even developed a long-term collaboration. As commented by the interviewee of Company F,

> "*If it were just a supplier-customer relationship, and talking to each other in that sense and negotiating hard, we will go really slow…We trust each other, we really developed a*

lot of things together, we are going to the market and talking to the market together… we have a very complementary benefits and advantages in it. It is a nice combination of our strengths and we each contribute our strengths" (E-3).

The key of the partnership is the trust and transparency between the two partners, which makes the progress much more efficient. As commented by the vice president of EMEA marketing of Company F: "*We have established a high degree of transparency between us where we are trying to make sure both of us are making enough money…more than the legal power, what is important between the partners is trust…*" (E-3). In addition, the two companies also share the risks in B2U. As said by one of the interviewees of Company A: "*In terms of brand, we share risks together. But our brand is more powerful than Company F, our risk exposure is bigger…In terms of technological solutions, there are some customers given the warranty. So in different ways we share risk, but the difference is they have the 'last-mile' delivery of the solution with the customer*" (O-1-3). The performance of the second-life battery system is guaranteed by Company F through warranties so the perceived risks concerning the batteries are alleviated for the end-customers.

Unexpectedly, the OEM in this case is also involved in delivering the final solutions to the end-customers. As discussed above, Alliance A will be leasing the product to the end-customers through their financing arm, from which Company A will benefit. The limitation of the BM is that the two companies do not benefit from the various energy services provided by the battery system after they sell or lease it. For Company F, the BM is to sell the battery storage system with bundled services in terms of installation and maintenance. The various grid-related energy service offers are provided by the aggregators who are connected to the end-customers through Company F. However, Company F mentioned the possibility of providing services in the future: "*We are not providing the service model for the time being but will probably do it in the future, because this market has just started*" (E-3).

Interestingly, when it comes to the competition from new batteries which will become increasingly cheap and better in performance, the interviewee of Company F shared a different point of view:

> "*The second-life batteries are old and they can do the job for a few years, but they have a value. Just like the example of second-hand car, might not be as comfortable as a new car but it's inexpensive and does the job. There are people who want a battery that's cost effective…So long as the value the system delivers is greater than the cost of transporting and packaging, this is a deal…It's an engineer's debate…the way of thinking about the value of something is not thinking that I could buy something that is better. Second-life batteries fit very well for certain applications… On the other hand, if you use new battery to do only frequency regulation, this economically is a waste*" (E-3).

4.5 Case study IV

4.5.1 Introduction to Case IV

In this case study, the OEM in focus is Company G, a German multinational luxury vehicle, motorcycle, and engine manufacturing company. Guided by the sustainable principles, a sub-brand of Company G was established in 2011 to design and manufacture plug-in electric vehicles. Two years after introduction, one of its EV series ranked as the world's third best selling all electric cars in history, with global sales achieving 50,000 units in July 2016. The sustainability concepts run through the whole production, usage and recycling stages of the EV lifecycle, and battery second use is a part of its EOL strategies.

The reason for choosing this case study is that Company G has been leading the European EV market. In addition, Company G anticipated the concern regarding EOL batteries well before its electric sub-brand was introduced and has been collaborating with universities, national labs, and utilities since 2009 to develop a "remedy" for second-life batteries. Company G has established partnerships with various engineering and energy companies to test and commercialise a second-life for retired batteries.

The data collection for Case IV is different from the previous case studies due to the difficulties in getting access to the partners of Company G. The author visited the headquarter of Company G in Germany and conducted an in-depth interview with the most informative person in B2U of the company, the program leader for Battery 2nd Life and Head of Development Stationary Storage Systems. A telephone interview was also conducted with the manager of Connected eMobility of Company G (North America). However, the author did not manage to interview the relevant partners/customers of Company G due to the lack of access. Therefore, secondary data were also used and the analysis is not restricted to a specific partner company, but at a more general level. The data from the conducted interviews as well as the documentation (e.g. company reports and newspaper articles) were analysed. The detailed list of interviews in this case study can be found in Table 4.15.

Table 4.15 List of interviews: Case study IV

Company	Stakeholder role	Region	Interviewees' position	Reference code	Time (mins)
G	OEM	North America	Manager, Connected eMobility	O-2-1	75
		Germany	Program Leader for Battery 2nd Life; Head of Development Stationary Storage Systems	O-2-2	128

4.5.2 B2U motivations, benefits and challenges

B2U motivations

Company G guarantees EV customers a residual capacity of at least 70% with an 8-year warranty for the battery and they think the remaining capacity is still good for storage applications. As one of the interviewees said, "*We believe repurposing the batteries in storage applications is the right thing to do in order to use the battery to the fullest capacity and to the fullest extent*" (O-2-1). From the environmental perspective, Company G is also concerned about the total carbon emissions from the battery: "*We are looking from a carbon emission perspective instead of a price perspective… In order to really reach the carbon emission requirements and sustainable approach that we are targeting on, we have to reuse the battery*" (O-2-1). It can be seen from the data that for Company G, the motivation for B2U is more from a resource efficiency and carbon emission perspective rather than a pure economic perspective.

B2U benefits

The envisioned B2U benefits for Company G include "*additional revenues streams*" from selling second-life batteries as well as the contribution to the "*holistic approach from a sustainability perspective*". At the society level, "*there are different use cases…renewable integration, peak shaving, back-up power or support EV charging, demand charge reduction or you do regulation in the energy market like frequency regulation or micro-grid installation…*" (O-2-1). The data show that in terms of the energy services provided by second-life battery systems the potential benefits of B2U also lie in the broader social and environmental value which contributes to a cleaner and more efficient transportation and power system.

B2U challenges

According to Company G: "*Right now the biggest issue with reusing batteries is more or less the cost and the competitiveness to new batteries which are only made for storage purposes. The second-life batteries are always with lower capacity and therefore, from a pure price per kWh perspective, we have a disadvantage*" (O-2-1). It can be seen from the data that Company G regards the cost of battery repurposing and the competition from new batteries as the biggest challenges. However, they also think it is important how you optimize the cost structure: "*…if you have to break down the batteries after the useful life in the car to the modules or even cells, then it is adding unnecessary costs…if you are able to reuse the battery pack as they are, then it is most effective way*" (O-2-1).

4.5.3 Business model description

This section presents the BMs of second-life batteries developed by Company G and its partners. Different from the previous case studies, the BM analysis in this case is not restricted to a specific partnership but for a more general pattern because Company G is very sensitive to it and the interview requests for the partner companies were all rejected. The activity system of second-life batteries is illustrated in Figure 4.9 which presents how Company G develops second-life batteries with its partners through a series of activities and transactions at the system level. The BM of Company G is then analysed at the firm level.

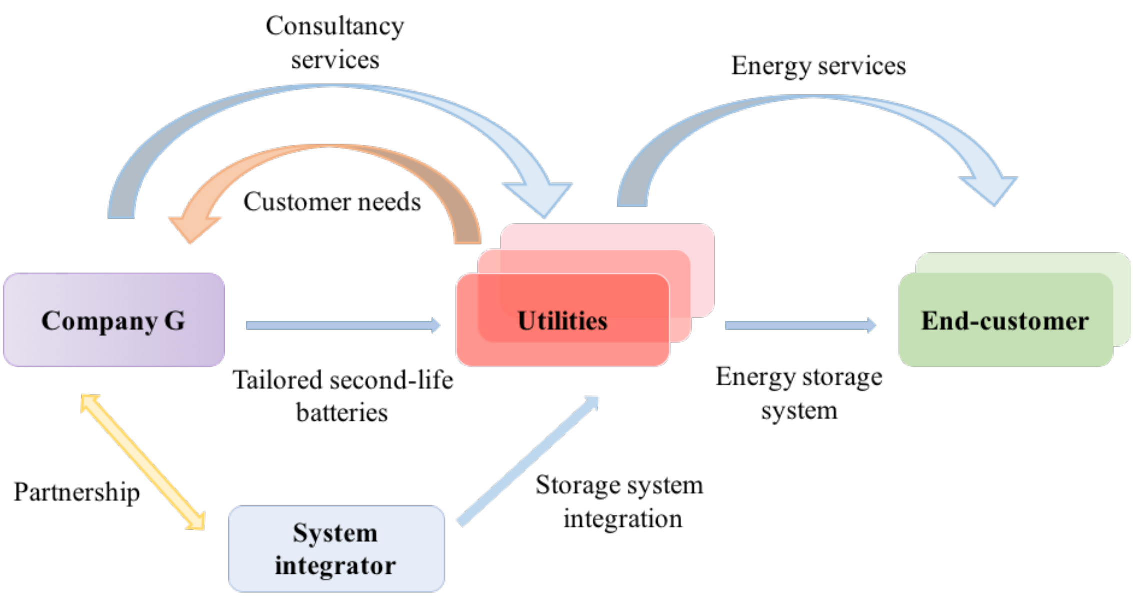

Figure 4.9 The activity system of second-life batteries: Case study IV

Activity system of second-life batteries

As shown in Figure 4.9, Company G develops tailored second-life battery systems according to their customer's needs and sells the batteries to their customers (e.g. utilities). In addition, they provide consultancy services to help their customers understand and optimize the value of the batteries. In the meanwhile, Company G also helps their customers find the right system integrator to do the storage system integration and get the system running for the customers. The customers then either take part in energy services through the system or sell the storage units to the end-customers (e.g. households). Depending on the contracts, Company G could take back those battery packs for recycling at the very EOL of the batteries.

Business model of Company G for B2U

For Company G, the BM is business to business (B2B) and the direct customers of second-life batteries are electricity utilities or charging network providers for example. According to one of the interviewees of Company G: "*The business model, we do consultant, that means we tell them (customers) where the market is. We hire people from energy companies so we can do consulting optimization, because some of them (customers) said I need batteries but I don't know exactly how…we have the technical solutions which means we have different architecture and simulation options so we have to tailor to what they need*" (O-2-2). The data show that Company G's value proposition is a portfolio of different technical solutions and tailor-made second-life battery systems based customers' needs. More importantly, they provide consultancy services, discussing the system architecture together with the customers, helping the customers find the right system integrator, and telling the customers where the market might be. As one of the interviewees said: "*We are building up a knowledge and know-how there in various projects we are doing, but this is more in a consulting capacity*" (O-2-1).

In terms of value added to the batteries, one of the interviewees of Company G explained: "*We are very engaged to understand how to bring the right aged battery to the perfect applications…we have all the knowledge and powerful people and I think we have the best software and analyzing tools, 100% quality control and historical data of the vehicle battery and we can create tailored system and give a set of the right batteries into it…*" (O-2-2). The data show that for Company G, the most essential value creation is the knowledge and expertise that are built into the battery system: "*The intelligence is in the battery system, and* *this is the key…after we take the battery out, we only need to change the software and then you can combine it with the right system interface because it is all about control algorisms and knowledge of the application*" (O-2-2). In addition, Company G has the knowledge of their cell chemistry internally which allows them to "*analyse the aging performance of the battery for its first and second life*". Company G discusses with their customers to do portfolio analysis and help them do the system integration through "*a portfolio of system integrators*". Besides, if the customers do not know how to run the system, Company G is also available to offer energy services for those customers.

In this BM, Company G is the second-life battery supplier and the developer for the tailor-made battery systems, as well as the B2U service provider. They capture value from selling the battery asset and helping customers develop the systems through the consultancy services. The value created for the environment is the reduction of lifecycle carbon emissions from the batteries. And the value for the society in general is the improvement in resource efficiency. The key attributes of Company G's business model for B2U are summarized in Table 4.16.

Table 4.16 Summary of key B2U business model attributes for Company G: Case study IV

BM attributes	Description
Customer value proposition	A portfolio of technical solutions and tailor-made second-life battery systems based on customer's needs; consultancy services in terms of the system architecture, system integration and potential markets
Value creation	The intelligence e.g. control algorisms built into the battery system; developing tailor-made battery systems that match the right aged batteries; portfolio analysis with customers and help them find the right system integrator; provide energy services for customers if needed
Value network position	Second-life battery supplier and tailor-made systems developer; B2U service provider
Value capture	Sales of the battery system; sales of the consultancy services
Social & environmental value	Reduced battery lifecycle carbon emissions; improved resource efficiency

Due to the lack of access to the partner companies of Company G, the author is unable to describe the detailed BMs of the other major B2U stakeholders. According to Company G and some secondary data (company reports and news), the system integrator is responsible for the construction work, buying the physical components, integrating them with second-life batteries and building the interfaces for the storage system that will be installed at the customer's site. One of the partner companies who are also the customers of Company G, develops a standard solution for home storage and sells the standard system to residential end-customers. Another partner of Company G is offering those battery systems to the end-customers as back-up storage systems and in the meantime, aggregating lots of the batteries for decentralized grid-related services such as the virtual power plant (VPP).

4.5.4 Review of the business model

In this case study, the OEM's business model for second-life batteries is selling the tailor-made battery system, plus consultancy services. The strength of the BM lies in the knowledge and expertise about batteries that Company G has built into the battery system, not only in the form of the software and algorithm development but also the consultant services provided to their customers. They have a portfolio of products and services that could be tailored to the customer's needs. They also have partnerships with some of their customers and in some cases, they have long-term collaborative development with their customers, helping them with the final solution development and optimization in the form of long-term consultant services. This helps Company G create and also capture more value from second-life batteries.

The other strength is that Company G incorporates the second-life for the EV batteries in their initial battery design (designing for B2U). For Company G, the B2U business unit is a part of the company's powertrain development, which helps optimize the value chain of the batteries both during its first life as vehicle batteries and second life as stationary storage batteries. The most important change they have made is to enable the whole battery pack to be reused in second life as it is without adding additional cost to disassemble the battery pack. In that way, they do not throw away the valuable components, e.g. the housing, the BMS, the heating/cooling functionality which is around the battery modules inside the pack which saves costs. As commented by one of the interviewees,

> "*From the architecture where we had to take the battery apart so that we could only reuse the modules, to now being able to use the battery as it is, that's really a huge step in order to prepare the battery from the design phase to be able to use it in a storage application*" (O-2-1).

The limitation of this BM is that in most cases the OEM does not own the battery asset – they sell the batteries and provide consultancy services to get the system running for their customers, but the potential value from various energy services provided by the battery system is not captured by the OEM. As said by one of the interviewees of Company G: "*We are more interested in selling the batteries and enabling additional revenue streams, but we are still considering whether it makes sense to run our own battery farms and just sell services*" (O-2-1). The data indicate that in the long run, Company G might change their BMs to provide energy services themselves instead of selling the battery asset.

Another limitation is that Company G is not providing warranties on the batteries: "*The biggest discussion we always have for second-life batteries is the warranty issues. We are usually not giving a warranty on used batteries because the life of the battery is still dependent on how it was used in the first application…*" (O-2-1). This might add to uncertainties for the customers and put second-life batteries in a disadvantageous position where their new battery counterparts are always sold with warranties.

For Company G, second-life battery is only one option embedded in their stationary storage business. And they think in the long run, the battery will last for a very long time after which the battery might not be suitable for stationary storage. "*In the future people will not worry about range and 70-80% residual capacity is probably not the end of the battery's first life… and those batteries after many years in the vehicle will not be promising for stationary storage because the will have less residual capacity left. This is why second-life is a chance, not the key...*" (O-2-2). Due to the uncertain volume of second-life batteries that will come back, the OEM is creating the same system design and architecture for both new and second-life batteries. According to the interviewee, "*It is a standard stationary storage device into the market, and if we have second-life batteries, we will bring second-life batteries in that; but if we run out of second-life batteries, we will produce new batteries for that*" (O-2-2).

This BM is also shaped and influenced by external factors. According to one of the interviewees, "*Utilities and grid transmission operators want residual capacity in the system and they want safety, safety, safety. It's not regarding battery safety, it's about availability safety. We have to overdo the grid infrastructure twice to be safe… whatever they do they* *want to double the capacity… It kills the business case*" (O-2-2). The other interviewee of Company F also commented, "*What needs to be done and can be done is by the regulators to accept battery storage as equal to alternative means of storing or creating energy to support the power grid*" (O-2-1). It can be seen from the large amount of confirming data that although not directly mentioned as B2U challenges, the regulation in grid-related energy storage market is one of the impediments for B2U and thus needs to be changed to facilitate the deployment of second-life batteries.

For brevity, the following case studies (Case study V, VI and VII) will be presented in a more compact format with limited explanations, but the key information and findings will be kept and presented.

4.6 Case study V

4.6.1 Introduction to Case V

In this case study, second-life batteries are developed by a joint venture of four companies: the OEM, the energy storage company, the energy trader and the battery recycling company. The joint venture has built 1,000 used EV batteries into a single storage solution and started operation of the system since the end of 2016. The OEM in focus is Company H, a German multinational automotive company. Through its subsidiary, Company H is active in both the automotive and stationary battery storage sectors. Company I is an energy storage company in Germany who has been cooperating with leading automotive manufactures in over ten countries. With its innovative charging and energy storage solutions, Company I aims to integrate EVs as well as second-life batteries into the power grid as an aggregated swarm storage. The reason for choosing this case study is that Company H is one of the OEMs intensively involved in both EVs and stationary storage. In addition, the 13MWh battery storage system built by the collaborative development is the world's largest of its kind made up of second-life EV batteries and it has been connected to support the German grid.

The data collection for this case study is composed of interviews and secondary data from documentation e.g. company reports and newspaper articles. The researcher visited Company I in Germany and conducted two rounds of in-depth interviews with the most relevant person, the managing director of Company I. Due to the lack of access, the German OEM (Company H) was not interviewed. Therefore, information regarding Company H were collected through the interviews with Company I as well as the secondary data. The detailed list of interviews in this case study can be found in Table 4.17.

Table 4.17 List of interviews: Case study V

Company	Stakeholder role	Region	Interviewees' position	Reference code	Time (mins)
I	Energy storage	Germany	Managing Director	E-4	206

4.6.2 B2U motivations, benefits and challenges

B2U motivations

For the German OEM (Company H), the main motivation for B2U is that retired EV batteries, though slightly degraded, remain operational after the service life guaranteed by the OEM. Company H wants to apply those batteries for stationary storage operation for at least 10 years longer in the most cost-efficient way. And for Company I, they see the value of second-life batteries in the energy storage market that could promote the German energy transition. As said by the interviewee, "*To accomplish the energy transition we need storage because of the volatile renewables in distributed production and you don't want to extend the grid…battery has an advantage in the energy system when it comes to response time…from the cost side, if you have second-life batteries, the system cost is even lower*" (E-4). The data show that the motivation for Company I to develop B2U is to utilise cost-effective second-life batteries to fulfil the German market needs for storage.

B2U benefits

The envisioned benefit of B2U for the OEM is additional revenues from the batteries. Also, B2U helps "*defer the recycling process which reduces the recycling cost because today you need to pay for recycling but we assume in the future you get money from that*" (E-4). For Company I who monetizes and markets the batteries, they benefit from the profits of trading the storage capacity into the energy market. At the society level, more battery storage helps the integration of intermittent renewables. And by providing energy services to the grid, B2U also helps make the grid smarter and avoid the expansion of the grid infrastructure in the future.

B2U challenges

The most critical challenge described by Company I is that "*currently the car manufacturers design the batteries only for being used in the car*" (E-4). Company I explained that during the B2U development with the OEM, the lesson they have learnt is that to optimise the whole cost structure "*you need to incorporate second use into the design*" (E-4). And they think it is very important to "*work together with the car manufacturers to design those batteries so that you can use them very efficiently, cheaply, durably and sustainably in second use applications*" (E-4). The large amount of confirming data from this case study indicate that the most critical challenge perceived is regarding the initial battery design which is not taking B2U into consideration.

4.6.3 Business model description

This section presents the BM of second-life batteries developed by the joint venture of Company H, Company I, the energy trader and battery recycling company. In this case study, the major B2U stakeholders discussed are the OEM (Company H) and the energy storage company (Company I) who repurposed and monetized the battery system in the energy market. The activity system of second-life batteries is firstly illustrated in Figure 4.10 which shows how stakeholders develop B2U through a series of activities and transactions at the system level. The BM of Company H and I are then analysed in detail at the firm level.

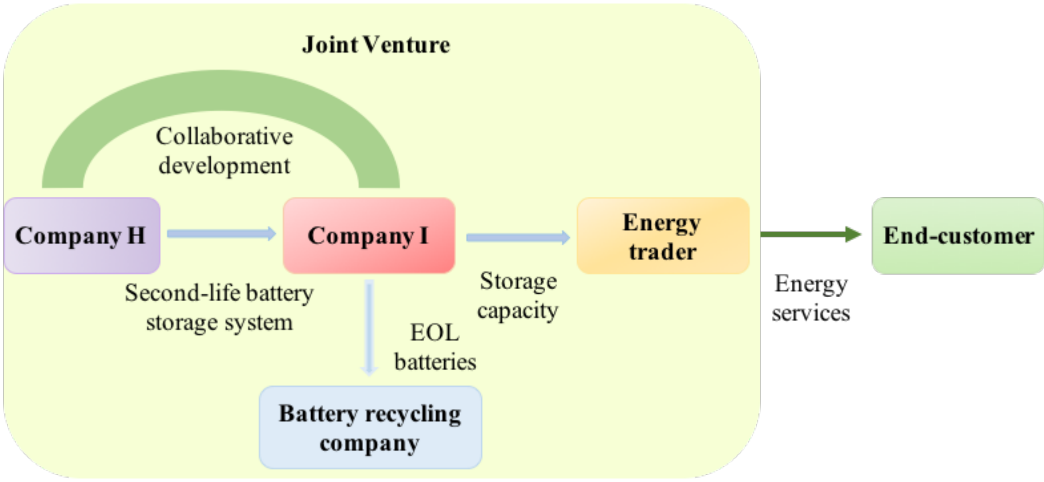

Figure 4.10 The activity system of second-life batteries: Case study V

Activity system of second-life batteries

In this case study, the OEM is both the battery provider and system integrator. They collect the battery packs and send them for testing and grading through outsourcing a battery testing company. After that, their subsidiary company is responsible for the storage system integration, adding the inverters, BMS and other power electronics around the second-life battery packs. As shown in Figure 4.10, Company I serves as the connection between the OEM and the energy trader to transform the retired vehicle batteries into the final storage solutions. Company I, as the energy market professional, is responsible for monetizing and marketing the battery storage system in the energy market in the most profitable way. Company I works closely with the OEM to continuously optimize the system and cost structure to help realize the value of the batteries. Company I operates the battery system and offers storage capacity in response to the market demand. They provide the storage capacity to the end-customers (e.g. grid operators) through the energy trader who has access to various energy markets. And at the very end of the battery life, they have the partner company responsible for the battery recycling.

Business model of Company H for B2U

For Company H, the BM is to repurpose and monetize second-life batteries through a joint venture. Its value proposition is the second-life battery systems that can be utilized in the energy storage market. Company H collects the old battery packs, sends them to an outsourced company for battery pack testing and grading, and then their subsidiary company is responsible for the storage system integration. Company H continuously works together with Company I to optimize the system on the battery side. They have the knowledge and expertise in battery storage systems because their subsidiary company is building new battery packs for both automotive and energy storage applications so "*they have the know-how to make second-life battery systems*" (E-4).

In this BM, Company H is the second-life battery provider and storage system integrator, as well as the knowledge partner in terms of B2U systems. They provide the battery systems for the joint venture and makes profit through sharing the revenues from the various energy services delivered by the batteries. The value created for the society and environment includes the deferral of the recycling process which incurs pollution and wastes and the improved resource efficiency. The key attributes of Company H's business model for B2U are summarised in Table 4.18.

Table 4.18 Summary of key B2U business model attributes for Company H: Case study V

BM attributes	Description
Customer value proposition	Second-life battery storage systems
Value creation	Collect retired battery packs, test and grade the battery packs through an outsourced company; integrate the storage system through their subsidiary company; optimize the system together with Company I
Value network position	Second-life battery provider and storage system integrator; knowledge partner in battery systems
Value capture	Shared revenue from energy services delivered by the batteries
Social & environmental value	Reduced pollution and waste caused by recycling; improved resource efficiency

Business model of Company I for B2U

For Company I, the BM is "*monetizing the battery pack and aggregating a lot of batteries into a bigger swarm, and then offering those batteries as storage capacity to the energy market*" (E-4). Its value proposition is the swarm storage capacity that can be used for various grid-related energy services. Company I works closely with the OEM to optimize the whole system for the most profitable applications. They integrate the OEM's battery knowledge with their expertise in energy storage. Company I is able to operate the battery system "*in the optimised points and it is kind of like a massage*" (E-4). They have the knowledge and expertise in the energy market and they know where and how to trade the battery storage most cost-efficiently. As said by the interviewee: "*We organize the whole setup and we have the technology to combine all those thousands of batteries, marketing them in the most profitable way to the energy market*" (E-4).

Company I positions itself as the energy market professional and swarm battery storage aggregator as well as the partner of OEMs who "*brings together the automotive and energy sides by monetizing the battery packs and realizing the value of B2U*" (E-4). They make the decision "*what kind of energy products to apply to those batteries and where*" (E-4). Company I offers the swarm storage capacity to different energy markets and shares the revenues. The value created for the society and environment includes improved stability of the grid which enables more renewable integration and avoids grid infrastructure upgrade. The key attributes of Company I's business model for B2U are summarized in Table 4.19.

Table 4.19 Summary of key B2U business model attributes for Company I: Case study V

BM attributes	Description
Customer value proposition	Swarm storage capacity that can be used for various energy services
Value creation	Optimise the battery storage system together with the OEM; operate the system optimally to extend the battery lifetime; organize the whole system setup and aggregate a swarm of batteries; trade the swarm storage to the energy market in the most profitable way
Value network position	Energy market professional, swarm battery storage aggregator as well as the partner of OEMs
Value capture	Shared revenue from trading storage capacity to the energy market
Social & environmental value	Improved renewable integration and avoidance of grid upgrade

4.6.4 Review of the business model

The application of second-life batteries in this case study is grid-scale energy services. The OEM's business model in this case is to retain the battery ownership while having a joint venture to help them monetize the batteries in the energy market. The strength of the BM lies in the sharing and integration of knowledge and resources from various partners in the joint venture. In this BM, partners bring their knowledge and expertise from various fields into the 'knowledge pool' to try to maximize the value of second-life batteries. As commented by the interviewee,

> "*It is more than just building a storage. It is also the knowledge about how to apply a storage best. You need to bring together the knowledge from both the automotive and energy storage…you need partners who know where to put the storage to gain the maximum value out of the battery*" (E-4).

Instead of selling the battery asset, the OEM brings the batteries into the joint venture and develop solutions for the batteries together with its partners. They share the revenues from the providing various energy services through the batteries. As said by the interviewee,

> "*Business model is not just about product but also services so you want to provide solutions… when it comes to second-life batteries especially and when it comes to grid or industrial application, customers just want to gain the monthly advantage but they don't want to get into any risk…*" (E-4).

The data indicate that the other strength of the BM is the service concept that takes away the risks in terms of purchasing second-life batteries – the batteries are not sold to anyone but are used to deliver the services for the end-customers. And because the batteries are owned by the OEM, there is no need for any warranty terms. More importantly, this BM allows the OEM to be able to continuously benefit from the various energy services provided by the battery over its entire second life. The value captured through this service-based BM is much higher than selling the cheap batteries as products.

The limitation is that the B2U cost structure is not optimised and according to Company I, the OEM needs to "*optimise something there in the future when it comes to the battery design*". For the time being, the data of battery quality over lifetime are not properly tracked by the OEM so that they need to outsource an external party to do the battery testing and grading which incurs extra cost. As the interviewee of Company I said: "*The lesson we have learnt is that you don't need to spend cost on that in the future. You need to track the data, being able to analyse the data and sort the batteries according to their quality for different applications*" (E-4). On the hardware side, the BMS inside the battery pack was designed only for the vehicle use and could not be reused for stationary storage application so that a new BMS needs to be built. In addition, Company I suggests "*using the OEM's purchasing power to apply inverter to the battery*" so that the whole system cost could be reduced. When talked about the cost that might be involved in optimising the battery design for B2U, the interviewee of Company I said: "*It is a matter of consideration, not cost*" (E-4).

This BM is also influenced by external forces. According to Company I, when it comes to B2U for stationary storage: "*It is actually not a matter of technology because technology is proven. It is more a matter of regulation – what we need is an open and economic-oriented energy market, especially when it comes to the whole grid market*" (E-4). The interviewee of Company I described regulation as a key in B2U:

> "*One of the keys is the regulator understand the value of batteries in the energy market and the role of batteries when it comes to renewables. The more volatile renewables you have, the more storage you need, and the more batteries you have to apply to those markets. We need regulators who understand that more and apply those markets to the most efficient*" (E-4).

4.7 Case study VI

4.7.1 Introduction to Case VI

In this case study, the OEM in focus is Company J, a French multinational automotive manufacturer. Company J launched EVs in 2011 and is now one of the EV leaders in Europe with around 100,000 EVs on the road. The reason for choosing this case study is that Company J has been leading the European EV market with a view of all the second-life batteries they are going to take back. Company J has been working with various partners from the energy sector to test and commercialise a second-life for retired EV batteries.

The data collection for this case study is composed of interviews and secondary data from documentation e.g. company reports and newspaper articles. An in-depth interview was conducted with the most relevant person at Company J, the program manager of energy services. Unfortunately, the researcher did not manage to interview the partners of company J due to the lack of access. Company K, an energy storage company which is one of Company J's partners, is used as an example in this case to explain how the OEM develops B2U solutions with its partners. The detailed list of interviews in this case study can be found in Table 4.20.

Table 4.20 List of interviews: Case study VI

Company	Stakeholder role	Region	Interviewees' position	Reference code	Time (mins)
J	OEM	France	Program Manager, Energy Services	O-3	57

4.7.2 B2U motivations, benefits and challenges

B2U motivations

For company J, the main motivation to commercialise second-life batteries is to "*reduce the total cost of ownership (TCO) of the EVs for the customers*". According to Company J, the revenue they will get from second-life batteries will be used directly for the reduction of EV price for the customers.

B2U benefits

According to Company J, the envisioned benefits of B2U include the promotion of EVs as well as reduced EV price and TCO for the EV customers. Company J is also aware of the benefits of B2U for the society and environment: "*(There is) a clear value on the circular economy around our batteries – we are doubling the battery life…this is very valuable for the environment…the benefit for the society is the circular economy which we call it virtuous loop of the EV battery*" (O-3).

B2U challenges

When it comes to the challenges of B2U, the interviewee of Company J said: "*One is related to regulation. Because the battery is considered to be dangerous goods, the transportation is very expensive…in some regulations, the second-life battery is not really defined…it shouldn't* *be regarded as waste otherwise there will be other regulations and complicated stuff. So the waste and transportation regulation is very important…*" (O-3). The second challenge is that because the batteries are "second-life" ones, it is not completely predictable in terms of battery SOH. In addition, there is no regular flow of second-life batteries which "*makes the business more difficult than if we have a steady supply*" (O-3). It can be seen from the data that the battery transportation regulation, the uncertainty in the battery SOH, and the managing of the second-life battery flow are the major B2U challenges perceived in this case.

4.7.3 Business model description

The activity system of second-life batteries is illustrated in Figure 4.11 which presents how Company J develops second-life batteries with its partner Company K through a series of activities and transactions at the system level. Due to the lack of access to Company K, the BM is analysed based on the interviews with Company J and secondary data. The BMs of Company J and K are then analysed at the firm level.

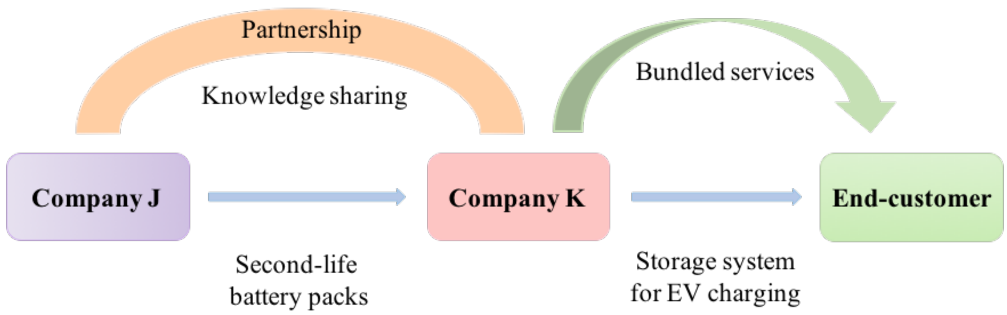

Figure 4.11 The activity system of second-life batteries: Case study VI

Activity system of second-life batteries

As illustrated in Figure 4.11, Company J sells the battery packs to Company K, the energy storage company. Apart from selling the asset, Company J also shares the knowledge and information on second-life battery performance and warranties the batteries on usage. Company K is both the customer and partner for Company J and they are responsible for system integration and building the final solution for the end-customers. In this case, second-life batteries are embedded in a stationary storage system that is designed to operate alongside the charging infrastructure to supplement the capacity from the local grid network connection. Company K provides warranties for the end-customers so the risks are shared by Company J and K. At the end of the battery second-life, Company J might take back the batteries for recycling based on the contract.

Business model of Company J for B2U

For Company J, the BM is to sell second-life battery packs. Its value proposition is the cheap second-life battery packs with all the components e.g. the BMS and the wirings reused. Company J has "*all the expertise and knowledge on the battery: the behavior of the battery, how it works and how it should work, all the safety stuff within the battery and this is clearly our role to provide information on the battery itself*" (O-3). They monitor the SOH of the batteries remotely and run simulations to evaluate the battery quality and predict battery degradation. They provide information on the battery performance to their partners based on the usage profiles in the second-life applications. In this BM, Company J is the battery supplier and battery knowledge partner. They make profit from selling the battery packs.

Business model of Company K for B2U

In this BM, Company K is the system integrator as well as the final second-life battery solution provider. They have the knowledge and expertise in power electronics and networks, and they are responsible for building a master BMS and the whole system integration. Its value proposition is a flexible, cost-effective and environmentally friendly energy management system to support fast chargers and grid load management. Sophisticated control software developed by Company K is integrated in the system to help customers maximize commercial value and operating efficiency of the batteries. The end-customers benefit from end to end support from the energy storage specialists of Company K in terms of installation, operation and maintenance services. The system can store electricity from on-site renewables or at times when the electricity is cheaper, and then release it as it is needed at a later time, which enables customer to reduce their energy cost. Apart from more efficient usage of energy, the system could also enable installation of fast chargers where electricity supply would traditionally only allow slower charging rates. This solution helps with the promotion of EVs by enabling more convenient and cost-effective fast charging. In addition, it enables rapid EV charging without overloading the local electricity supply and thus contributes to a more stable and sustainable power network.

4.7.4 Review of the business model

The strength of the BM is that in most cases (80-90%), unlike other OEMs, Company J is leasing the batteries for the EV customers which means that the battery is the property of Company J. When the batteries degrade to a certain capacity, Company J will change the batteries for the customers for free. In that way, Company J has a clear view and more control of the flow and quality of second-life batteries. The other advantage is that they use the battery pack as it is which helps reduce the system cost. According to Company J,

> "*We use the battery pack as it is in the car and take everything out and reuse it… using the pack help us to have advantage in the price and also we use the cable, the BMS that are inside the car and that makes our life much easier, first technically and also in terms of business model it makes the battery cheaper*" (O-3).

The limitation of the BM is that Company J is mainly selling the battery asset which prevents them from further benefiting from battery value in the energy market. However, Company J thinks that it is because the revenue sharing potential in this application is very small and also it is not an established market. They are testing other BMs where they design and develop the final solutions together with their partners and share the revenue on the stationary storage market.

4.8 Case study VII

4.8.1 Introduction to Case VII

In this case study, the OEM in focus is Company L, a Japanese multinational automotive manufacturer. Company L is the world's market leader in hybrid EV sales and one of the largest companies to encourage the mass-market adoption of hybrid EVs across the globe. Company L started B2U business in 2011 and has been testing and commercializing second-life batteries from their hybrid EVs across different regions. An in-depth interview was conducted with the most relevant persons at Company L, the program general manager of New Business Planning, the project manager of Environmental Affairs and the group manager of the Planning Department. The detailed list of interviews in this case study can be found in Table 4.21.

Table 4.21 List of interviews: Case study VII

Company	Stakeholder role	Region	Interviewees' position	Reference code	Time (mins)
L	OEM	Japan	Project general manager, new business planning; Project manager, environmental affairs; Group manager, planning	O-4	106

4.8.2 B2U motivations, benefits and challenges

B2U motivations

For Company L, since they use nickel-metal hydride (NiMH) batteries, recycling is economically better for their batteries in that nickel is very expensive. However, the batteries will be recycled in the end anyway and Company L wants to "*use it more to generate more value if the battery is still alive*". According to Company L, "*We started our B2U business because we realised that batteries were still good after vehicular usage…we don't want to* *recycling viable/alive batteries, we want to use them until they die*" (O-4). From the environmental perspective, Company L also considers B2U as a more environmentally friendly option than battery recycling. As said by one of the interviewees, "*Economically it is good to recycling batteries but environmentally it is not good – it will need a lot of energy to process. But if we can reuse those batteries, we just need to check the batteries and they can be used for another ten years which I think is quite good for the environment*" (O-4). It can be seen from the data that the B2U motivation for Company L is more from the social and environmental perspectives rather than the pure economic profit aspect.

B2U benefits

The envisioned benefits of B2U for Company L include additional value opportunities in the energy market and the promotion of company image in terms of carbon footprint and resource efficiency. For B2U customers, second-life batteries provide a cost-effective solution for better energy management. In terms of society and environment, B2U prolongs the battery lifetime and defers the recycling process, which helps reduce the environmental impact and resource exploitation.

B2U challenges

For Company L, the biggest challenge regarding B2U is that they do not have control over the old batteries retired from EVs in some countries. As said by one of the interviewee, "*Our neighbouring countries buy the old batteries at higher price…and get nickel from the batteries…also there is no regulation to prevent such individual exports*" (O-4). The other challenge described by the OEM is the cost of the battery storage system as a whole. Currently the payback time of the battery system is 6-7 years and the system cost should be further reduced to shorten the payback time and attract more customers. It is important to reduce not only the battery cost, but also the cost of inverters and battery controllers which are currently very expensive.

4.8.3 Business model description

In this case study, the major B2U stakeholder is the OEM. The activity system of second-life batteries is illustrated in Figure 4.12 which presents how Company L transforms second-life batteries into the final solutions for the end-customers at the system level. The BM of Company L is then analysed at the firm level.

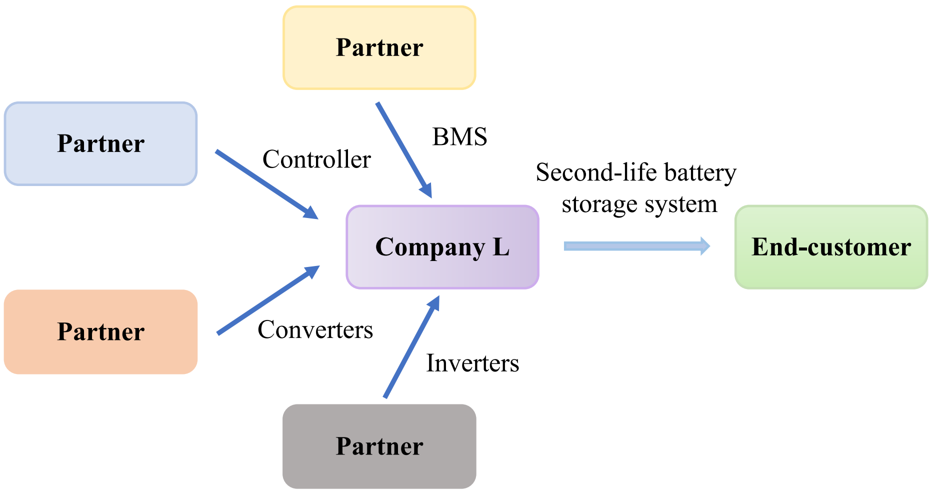

Figure 4.12 The activity system of second-life batteries: Case study VII

Activity system of second-life batteries

As shown in Figure 4.12, Company L integrates all the resources from its partners, and sells the second-life battery storage systems to the end-customers. Unlike previous case studies, Company L vertically integrates all the B2U activities in this case. They are both the second-life battery and the final solution provider. The environmental division of Company L established the B2U processes and collected batteries from retired hybrid EVs all over Japan. They have collaborations with different partners who assist them in developing the inverters, the BMS, the controllers that best fit their battery system. Company L then integrates the battery storage system and offers those devices to their customers to help them reduce the energy cost. At the very end of the battery life, Company L will take back those batteries for recycling.

Business model of Company L for B2U

For Company L, the BM is to integrate and sell second-life battery storage system. Currently, 80% of the customers are the car dealers of Company L and 20% are their parts manufacturers. Its value proposition is the cost-effective battery storage device that can be coupled with LED and on-site PVs to cut peak demand charges and reduce electricity bills. Company L did a lot of battery durability tests so that they can "*see the status of batteries and roughly predict how many cycles can be further used*". The system is guaranteed for the customers for 8 years and if something bad happens to the battery Company J will change the battery for free. Company J has the knowledge and expertise in the batteries and they integrate all the resources needed to build an energy storage system from various partners. According to one of the interviewee, "*We are the best people who know about our batteries and we can handle the high voltage batteries*". In this BM, Company L is both the second-life battery supplier, system integrator and the final second-life battery solution provider. They make profit from selling the battery storage systems but apart from that, they also consider the promotion in the company image as the value capture. As said by one of the interviewees,

> "*Because we ask our car dealers to use our second-life batteries, it is also an appeal to the customers…Customers would be happy to know that their used batteries could be applied in a next application. The promotion of our company image is a very big effect for us*" (O-4).

4.8.4 Review of the business model

The strength of the BM is that the ownership of the batteries is always with the OEM and they are the direct solution provider, which means they could capture more value out of the batteries. The limitation of the BM, however, is that as an automotive OEM their knowledge and resources in energy storage, and thus the potential applications they can apply the batteries in are very limited. In addition, the product selling model prevents them from further benefiting from the potential value of second-life batteries in the energy market.

One of the interesting points mentioned by Company L is the development of a quick testing device at the car dealers to test the battery quality before transportation. In that way, the transportation of bad quality batteries could be avoided and transportation cost reduced. The other thing is that the dealers could offer higher price to the customers for the good conditioned batteries so "*it could also be a good incentive for car drivers to take care of their batteries*" (O-4).

4.9 Out-of-case: Supplementary interviews

Due to the emerging nature of the B2U industry, the commercialisation cases of second-life batteries are very limited. It is observed that some companies, though haven't launched any commercialization initiatives, have been investigating into B2U for a long time in terms of R&D. Those companies could provide substantial implications for this study. To gain a better understanding of the industry as a whole, eleven complementary interviews were conducted, in addition to the main case interviews, with various stakeholders across different regions including Japan, China, Europe, US and Canada. These interviews include two giant automotive OEMs in Japan and China (O-6, O-7), one of the biggest batteries manufacturers in China (BO-1), one of the largest vehicle and battery recycling companies in China (BR-1), one of the biggest electricity utilities (EU-1) and independent power producer and supplier (E-5) in Japan, a safety consulting and certification organization in the US (S-1), an energy storage start-up in Germany (E-6) and three experts on energy storage from universities and research organizations (EXP-1, EXP-2, EXP-3). The supplementary interviews provide insights in many aspects including the perceived challenges and benefits of B2U from various stakeholders and comments on the existing business models of B2U as well as the policy context in different countries. Taken together, the data from the supplementary interviews presents a more comprehensive landscape of the B2U industry. They were treated as independent sources of information, either exploratory or supplementary depending on when in the research process they were conducted, and used to validate findings from the main cases.

It is interesting to note that most of the Chinese companies in particular, are very policy-driven in terms of B2U development. The major EV companies and battery manufacturers are well aware of the opportunities brought by B2U, but they are reluctant to invest in B2U due to the lack of policy support. The interviewed companies showed that they would like to wait until there are clear policies regarding B2U. Currently, automotive and battery manufacturers are running various B2U pilot projects to test the technology and economics of second-life batteries. The Chinese government is implementing rules on battery second-life in August 2018 and it would be interesting to follow up how Chinese companies react to that.

4.10 Case summary

In this chapter, seven case studies of B2U business models are described to show how manufacturing firms are commercialising a second-life for retired EV batteries. The case studies not only show the B2U business models developed by different companies, but also how a company diversifies its BMs with various partners for different applications (e.g. residential, industrial and commercial, and grid scale) depending on the markets and regions. The description in this chapter consists of three main parts: a) an overview of the motivations, benefits and challenges of B2U that explains why companies develop second-life batteries, what are the envisioned benefits and challenges confronted or expected; b) an analysis and description of the BMs in individual case studies that detail on the value creation and capture from second-life batteries; and c) a comment on each of the BMs. Taken together, the presented case studies reflect the nascent stage of the B2U industry as a whole. Based on the individual case analysis and findings, the next two Chapters present further analysis of the BMs across the cases and discuss the findings.

5 Cross-case analysis

In the previous chapter, seven case studies of B2U business models were individually analysed. The empirical case studies were presented first in the form of a narrative description of the B2U 'stories', and second as a summary tabulation of emerging themes identified in individual case studies. When reflecting across the seven case studies, there are patterns emerging. This chapter aims to answer the generic question: what are the patterns across all the cases? Five key questions are posed to help explain the patterns, namely, a) Why do companies do B2U and what are the benefits; b) What are the critical challenges of implementing B2U; c) How are automotive OEMs currently creating and capturing value from B2U; d) How are firms currently designing B2U business models; and e) What are the factors that influence B2U business model selection. A cross-case analysis of the seven case studies is presented to take the analysis to the next level of data reduction and answer the five questions. The cross-case analysis adopts a combination of case-oriented and variable-oriented strategies (Miles et al. 2014). The findings are presented as answers to the five questions posed.

5.1 Why do companies do B2U and what are the benefits?

The motivations of B2U for the major stakeholders have been discussed in all seven case studies in Chapter 4. It can be seen from the data that B2U stakeholders are mostly motivated by the economic profits from applying second-life batteries in energy storage, for example, additional revenue streams for the automotive OEMs or cost reduction for storage system providers to fulfil energy market demands. There are cases, for example cases III, IV and VII, where the OEMs also mentioned the environmental benefits as one of their motivations: B2U provides a more environmentally friendly EOL option than recycling. The envisioned benefits analysed in the seven case studies show the existence and importance of other sources of benefits available for multiple B2U stakeholders.

For the OEMs, apart from obtaining additional revenues, B2U could help quicker EV adoption because the cost structure and residual value of EVs are improved. OEMs could also benefit from promoted corporate image by offering B2U which is a more environmentally friendly EOL solution than battery recycling or disposal. In addition, recycling currently incurs costs due to the low volume of retired EV batteries but it is expected that in the future recycling might generate profits. B2U could therefore defer the recycling process for those batteries which helps OEMs reduce or avoid the cost of recycling.

For energy or power companies, by using cheaper second-life batteries they could build more cost-effective storage systems. They also benefit from an expanded customer base which would otherwise be difficult to access with a costly system. In some cases, through working with the automotive OEMs, the energy companies (especially start-ups) also benefit from the power of the OEM's brand which makes it easier for them to enter the market.

The end-users of the second-life battery system benefit from more intelligent management of their energy usage profiles. Battery storage systems enable more efficient demand-side management that helps reduce the energy cost for consumers. Depending on the energy market, the end-customers could also profit from various grid-related energy services to generate additional revenues.

Depending on the applications for second-life batteries, there are various social and environmental benefits delivered through B2U. In general, battery storage could facilitate more efficient renewable integration and reduce the demand peak, which in turn enables more efficient operation of the power plants (Divya & Østergaard 2009). In the long run, it helps defer or even avoid the needs for new power plants and grid infrastructure upgrade, which could reduce the overall environmental impact from the power sector and reduce energy bills for tax payers. Moreover, by making EVs and energy storage more affordable, B2U has the potential to contribute to a cleaner transport and electricity system.

The above analysis shows that there are actually much more benefits available from B2U that the OEMs are not currently capturing. The economic returns of selling the battery asset reflect only a small part of the overall benefits from B2U. In most cases, the value delivered by second-life batteries in energy storage is not captured by the OEMs. Moreover, the wider social and environmental benefits of B2U are often neglected which could constitute important sources of value opportunities. Based on empirical data from various stakeholders involved in B2U, this study analyses the economic, social and environmental benefits from B2U for multiple stakeholders, and delivers a comprehensive view of the overall B2U benefits.

However, in the nascent stage of B2U, there are many challenges facing B2U stakeholders that hinder them from further extracting the value from second-life batteries. It is thus essential that B2U stakeholders firstly understand the potential value of second-life batteries to better evaluate the cost and benefits of B2U and design BMs to better achieve that value.

5.2 What are the critical challenges of implementing B2U?

Despite the envisioned benefits of repurposing retired EV batteries for energy storage, there are manifold challenges regarding B2U that could significantly reduce the value of second-life batteries. In Chapter 4, the B2U challenges confronted by major stakeholders were discussed in each case study individually. This section brings together the challenges across the cases and offers an analysis of the key B2U challenges that are most often mentioned by stakeholders. The challenges are grouped into four critical challenges: competitiveness, uncertainty, design and regulation. The four critical challenges are refined and generalised from the individual case studies to reflect the more general nature of the cross-case findings. For example, the ‘uncertain flow of batteries’, the ‘uncertain second-life battery performance’ and ‘customers’ concerns over second-life batteries’ are grouped into the challenge of ‘uncertainty’. The four critical B2U challenges are summarised in Figure 5.1.

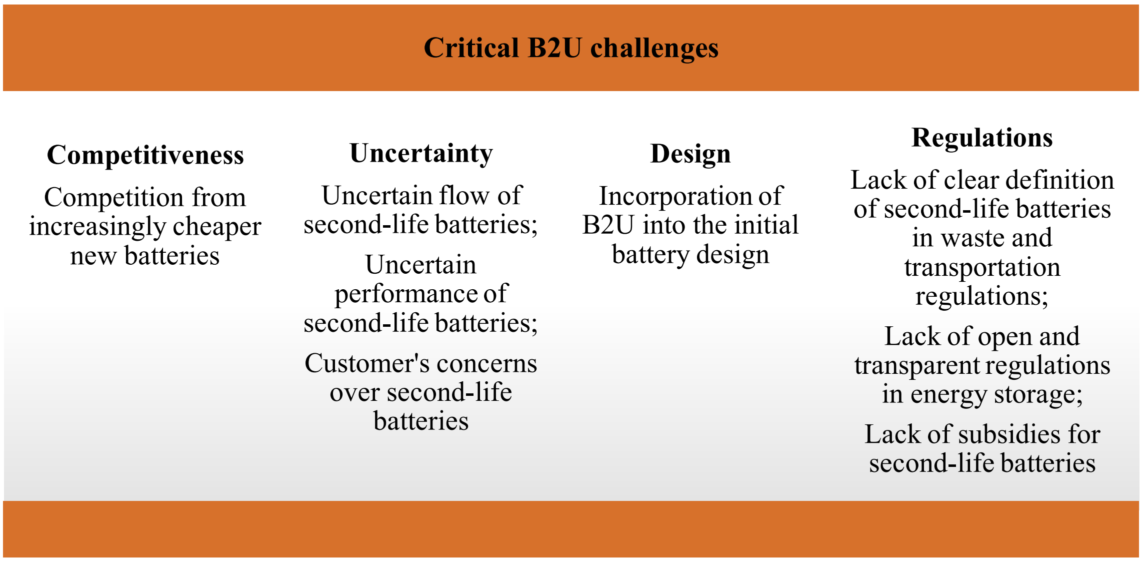

Figure 5.1 Summary of critical B2U challenges

Competitiveness

The competition that comes from new batteries were commented by interviewees from all seven case studies. In four out of the seven cases (case I, II, III and IV), the competition from increasingly cheap new batteries was described by the OEMs as one of the most critical B2U challenges. The existing data show that currently, the relatively cheap price of second-life batteries compared with new batteries is regarded as the main motivation for many companies to develop B2U. However, it is also expected that by the time the 8 or 10-year-old batteries are taken out of the cars (Richa et al. 2014), there will be new generations of batteries in the market with not only cheaper price but also much better quality and performance. The increasingly cheaper new batteries would make the life of second-life batteries more difficult. In that case, the cost competitiveness and thus the attractiveness of second-life batteries would be diminished. The OEMs are now trying to reduce the cost of battery repurposing, for instance, using the whole battery pack as it is to avoid costs regarding opening the pack, so as to keep the cost competitiveness of second-life batteries (case IV, V, and VI).

Uncertainty

a) Uncertain flow of second-life batteries

The other critical challenge most clearly mentioned by the OEMs is managing the flow of second-life batteries (case I, III, VI, VII). Unlike new batteries, the volume of second-life batteries that will come back to the OEMs is somewhat out of control because it depends on the customer's behaviour – when they retire the batteries, and whom they return the batteries to. Most studies have predicted or modelled an EV battery lifespan of 8-10 years which is consistent with the length of the battery warranties provided by many OEMs (Richa et al. 2014). However, the battery lifespan is uncertain due to many factors such as charging patterns which vary from user to user. Besides, the traditional mechanism for end-of-life vehicles (ELV) is that ELVs are returned to vehicle dismantlers who will pass on still valuable components to refurbishing, remanufacturing or recycling specialist. There is currently no established system for OEMs to collect retired batteries from EV owners.

The uncertain lifespan of EV batteries coupled with a lack of battery collection system add to the uncertainty in the volume of second-life batteries available for the OEMs. And if the OEMs sell second-life batteries to their customers, the uncertain return flow of the batteries also causes anxiety for the purchasers of the battery due to a lack of steady supply. This would make the B2U business more difficult, especially for large-scale applications which require a steady supply of batteries with a large volume.

In case I, for example, the energy storage start-up (Company B) showed their concerns about the amount of second-life batteries available from the OEM. They are not too concerned now because the scale of their business is small. However, they said they need to be sure about the volume in order to scale up their businesses, otherwise they will stop using second-life batteries in the future. This is not mentioned in case II and it might be because the core business of Company E is using new batteries, and second-life battery is just an option for them. And in case V, the OEM's business model is service-based rather than selling the batteries so the OEM does not need to make their customers feel 'secure' about the battery supply. The OEM in case IV did not indicate this challenge but they said they have sold out of second-life batteries which implies a lack of steady battery flow.

In the author's view, it seems that the scale of second-life batteries would solve this problem in the future but it might also generate more competition for the volume out there. When second-life battery supply scales up, it becomes a competitive issue where the best business models that offer the highest price will get the most batteries.

b) Uncertain second-life battery performance

The uncertainty in the remaining battery lifetime and degradation performance in various energy storage applications is perceived as another critical B2U challenge for both the second-life battery providers and buyers (case I, III, V and VI). Unlike new batteries that are designed for energy storage, the lifetime and degradation of second-life batteries are quite uncertain, depending on both how they were used in their first life in the EVs and how they are going to be used during their second life in stationary storage applications.

This uncertainty is said to be caused by: a) the lack of systemic and sophisticated on-board diagnostic data collection; b) the lack of effective data analysis; and c) the lack of sharing with downstream stakeholders on the battery health over its first life in vehicles. One of the OEMs said: "*We have the global data centre so the data is enough. What matters is how we can analyse the data. For the time being, we can't precisely predict the remained lifetime but it is under the way…*" (O-1-1). However, the interviewee of one of the downstream energy companies said: "*They (the OEM) don't track all the information we would like to have…at least not in such an efficient way as we would like it to be…If they track all the information, we would get much more proper picture about the quality of the battery at the end of life…*" (E-4). In addition, one of the interviewees commented on current battery testing: "*This testing is not going to tell you the performance forward because that requires a lot more information from the OEM*" (L-1). It can be seen from the data that there is information asymmetry between the battery provider and downstream stakeholders, which indicates the need for closer communication and information sharing between B2U stakeholders.

Besides, there is a lack of understanding of second-life battery aging behaviours in specific energy storage applications and a data sharing platform among stakeholders. Since each battery ages differently under the varying historical operating conditions in the EVs and complex usage profiles in energy storage, it is difficult to predict the exact aging behaviour of the batteries during their second-life. Without a proper tracking of the historical usage data of the batteries and evaluation of the second-life battery performance, it is not very likely that the OEMs could persuade customers to buy their second-life batteries in the long term.

c) Customers' concerns over second-life batteries

The data show that from the customer's side, the major challenge of acquiring second-life batteries is their concerns over second-life batteries (case III and IV). As one of the interviewees said: "*Another challenge is that people often have low price expectation for second-life batteries, so we have to tell them the value of the system…*" (E-3). In general, customers have a bias against used products – they feel insecure about second-life batteries and they have low price expectations. Besides, customers have poor understanding of the value of second-life batteries. They do not have the knowledge about the functionalities of the battery storage system, and they lack the skills or experience for operating the system. Those concerns could strongly influence customers' buying decisions and impair the real value of second-life batteries.

Design

From the B2U repurposer's perspective, one of the challenges of B2U is in regards to the initial battery design. As commented by one of the interviewees in case V: "*Currently the car manufacturers design the batteries only for being used in the car*" (E-4). The data show that the battery repurposing cost is significantly affected by how the batteries were initially designed. For example, if the BMS does not properly track and collect the battery usage data over its first life in EVs, the battery state of health (SOH) could not be evaluated and thus batteries would need to be sent to a third party for testing. This incurs extra cost in battery transportation and testing. Besides, if the components inside the battery pack such as the BMS are not compatible with stationary storage applications, a new BMS needs to be built and implemented to the battery system which brings additional costs for battery repurposing.

It is obvious that the car manufacturers will always prioritise the battery design for the EVs. However, a systemic design thinking that incorporates second-life repurposing into the initial battery design would greatly smooth the whole repurposing process and reduce/avoids relevant costs. And as one of the interviewees commented: "*It is a matter of consideration, not cost*" (E-4). Some OEMs are aware of the importance of design for repurposing and have taken measures either in the form of battery architecture re-design or the improvement of battery control and data tracking system (e.g. case IV).

Regulation

In terms of regulation, the data show that there are three major challenges depending on the countries and regions. The first is regarding the waste and transportation regulation. Currently, in most countries second-life batteries are not clearly defined in the regulation. As one of the interviewees of case VI said: "*Because the battery is considered to be dangerous goods, the transportation is very expensive…the second-life battery is not really defined…it shouldn't be regarded as waste, otherwise there will be other regulations and complicated stuff*" (O-3).

The second regulatory challenge is regarding battery storage for the energy market. As commented by one of the interviewees in case VI, for example, "*If the regulation is not open, the business model could not fly*" (O-3). The large amount of confirming data from other interviews also show that the electricity market regulations in most regions are not open and transparent yet, which might kill many potential business cases. Stakeholders in the case studies expect that the regulators could understand more about the role and value of batteries in the energy market and accept battery storage as equal to other means of storing or creating energy to support the power grid.

The third regulatory challenge is that in some regions such as California, there are incentive programmes that only subsidise new batteries but not second-life batteries, which is unfavourable for second-life batteries to compete in the energy market.

Reliability check and new findings

The B2U challenges discussed above are not the complete list of challenges identified from the case studies. They are the challenges that were directly addressed by the interviewees and considered to be applicable at a more general level. Those challenges were brought to the list (Figure 5.1) because even if there is clear evidence from only one case, they are believed to be relevant to multiple cases. Some case-specific challenges were discussed in individual case studies but not brought to this cross-case analysis (e.g. the lack of transparency from the OEM in case I). The author then reviewed the critical B2U challenges against the data to present a limited reliability and bias checking list (Table 5.1). The aim is to check whether there is indirect supporting evidence or contradictory data missed. Two tick marks represent strong evidence backed up by direct statement of interviewees, one tick mark represents weak evidence (e.g. things they showed concerns about but not directly mentioned as a challenge), the circle means neutral attitude, the dash means the data is not available, while cross mark (if any) represents contradictory evidence.

It can be seen that there is no contradictory evidence regarding the summarised B2U challenges. Interestingly, interviewees of case III, V and VI showed different perspectives on the challenge of the decreasing cost of new batteries. When asked about the competition from new batteries, one of the interviewees from Company J (case VI) said: "*We don't think it is a challenge because we always think that new battery price will come down but again, second-life batteries will be half cheaper than new batteries anyway. Our objective is to follow the reduction of the new battery price*" (O-3).

Table 5.1 Reliability check of the critical B2U challenges against the seven case studies

Critical B2U challenges		Case I	Case II	Case III	Case IV	Case V	Case VI	Case VII
Competitiveness	Decreasing cost of new batteries	✓✓	✓✓	✓✓	✓✓	O	O	✓
Uncertainty	Uncertain flow of batteries	✓✓	--	✓✓	✓	--	✓✓	✓✓
	Uncertain performance of batteries	✓	O	✓✓	✓	✓	✓	O
	Customer concerns	O	O	✓✓	✓	--	--	O
Design	Incorporation of B2U into battery design	✓	✓	--	✓	✓✓	--	--
Regulation	Lack of clear definition of second-life batteries	--	--	--	--	--	✓✓	--
	Lack of open and transparent regulations in energy storage	✓	O	✓✓	✓	✓	O	--
	Lack of subsidies for second-life batteries	✓✓	✓✓	--	✓✓	O	--	--

Company J was aware of the competition from new batteries and its influence on their business: they would keep the price competitiveness of second-life batteries by decreasing their price accordingly. They did not perceive the decreasing cost of new batteries as a challenge. However, in the author's view, it might still cause concerns for Company J if, in the future, the price of new batteries comes down to a certain level that is about the same with the battery repurposing cost. And if Company J continues their current battery selling BM, it might be difficult for them to develop business cases for second-life batteries. In addition, new battery price is expected to come down over time, and for second-life batteries to remain half the price (Figure 5.2 is given as an example), the cost of repurposing second-life batteries needs to be brought down by learning (e.g. better data management systems) and scale. However, as shown in Figure 5.2, if we assume the lifespan of an EV battery to be 8 years, a new battery (A1) would appear 8 years later as a second-life battery (A2) and if the second-life battery is half the price of the year-8 new battery (B1), it is sold lower than half of its original cost. Therefore, the idea of selling the second-life battery at half-price of the new battery is actually half the price of current battery technologies, and less than half of the value of the battery is captured in economic terms.

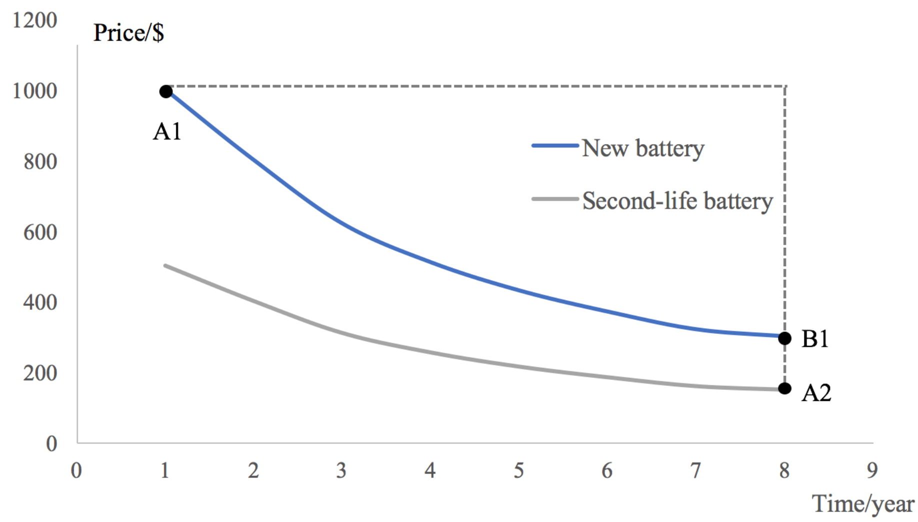

Figure 5.2 An example of the price of new and second-life batteries over time

Company I, the energy company in case V, shared the view regarding competition from new batteries, but from a different perspective. When asked about how to compete with new batteries, one of the interviewees said: "*The matter is the business model is different. Imagine you are a car manufacturer, you have a value in the car which doesn't work for the car anymore…but it still can make a lot of money somewhere else…they don't want to sell those batteries and make money through those batteries – they just want to apply them to the most cost-efficient way*" (E-4). According to Company I, the BM for second-life batteries shouldn't be regarded the same as new batteries: the OEMs should try to maximise the value of the batteries rather than selling the batteries and compete in price.

Unexpectedly, the OEM and their energy partners in case III saw the competition from new batteries from different perspectives. The OEM (Company A) regarded the decreasing new battery price as one of the most critical challenges while the energy company (Company F) said: "*It's an engineer's debate…the way of thinking about the value of something is not thinking that I could buy something that is better. Second-life batteries fit very well for certain applications…*" (E-3). According to Company F, second-life batteries have their own markets and the point is to find the best suitable applications for those batteries.

In summary, most of the OEMs regard the competition from increasingly cheap new batteries as the most critical challenge for B2U. However, in most cases, that challenge is still perceived through the product selling logic. What is interesting is that some companies are starting to jump out of the 'sell-and-disengage' logic box and think about the potential value and innovative business models of B2U, which could rescue second-life batteries from the 'trap' of the price debate.

These four dimensions of critical B2U challenges (Figure 5.1) are the first to have been extracted from empirical data and provide a fresh overview of the factors that might impede B2U development and impair the potential value of second-life batteries, which the author proposes as a new insight. At the current emerging stage of B2U, the value of second-life batteries is still poorly understood by both practitioners and academia, let alone the general consumers. As discussed in the previous section, it is clear from all cases that there is actually more value available that the B2U firms are not fully accessing. The real challenge is realizing a potential that the majority of observers and researchers seem to think exists but is not actually very good at extracting the value. Joint efforts from stakeholders across sectors are needed to overcome the critical B2U challenges to achieve the potential value of second-life batteries.

5.3 How are automotive OEMs currently creating and capturing value from B2U?

The complete set of interviews shows that automotive OEMs are creating and capturing value from B2U in different ways. In most cases, OEMs are adopting battery selling as their main BM. However, due to the lack of knowledge and resources in applying the batteries to the energy market, the OEMs do interact, in different ways and to different extents, with stakeholders from the energy sector to help develop and deliver the final solutions to the end-customers. In this study, the key stakeholder who offers the final energy storage solution to the end-customers is termed 'B2U solution provider'. The major stakeholder roles generalised from the seven case studies are the automotive OEM, the B2U solution provider and the end-customer.

The data show that the main differences between the BMs in the case studies originated in the various relationships and interactions between the OEM and the B2U solution provider. The degree that the OEM integrates B2U into their businesses varies from nearly zero to full integration. Compared across cases, it was found that in general, the value generated from B2U for the OEMs increases as the degree of integration raises. In case V, for example, the OEM keeps the ownership of the batteries and benefit from the energy services provided by the batteries during their entire second-life while in case I the OEM only get additional revenues through selling the batteries at a very cheap price ($85/kWh as referred to by one of the interviewees). This indicates the degree of integration as a key factor in the value creation and capture for the OEMs. Based on the BM analysis in the seven individual case studies, this section presents a typology of existing B2U business models to illustrate how key stakeholders across the automotive and energy sectors interact to create and capture value from B2U in different ways.

The BMs examined from the seven empirical case studies can be categorised into three types: standard BM, collaborative BM, and integrative BM. These categories correspond to the various relationships between the OEM and B2U solution provider, namely, a) pure supplier-customer relationship; b) collaboration; and c) the OEM internalising the role of the B2U solution provider. Within the collaborative BM type there are subtypes, depending on the degree of integration and the relative dominance of stakeholders in the final solution development. Examples from the case studies are given for each subtype.

A schematic illustration of the typology is shown in Figure 5.3. The degree of integration in the BM types increases from left to right. The boxes represent key stakeholders involved in B2U: the OEM, the B2U solution provider, and the end-customer. The height of the OEM box represents the relative degree of integration. The red arrow represents the flow of battery ownership and green arrow represents the knowledge and information flow between the OEM and B2U solution provider, while the purple arrow represents the delivery of final solutions to the end-customers. The distribution of the seven case studies in the BM typology is also shown at the bottom the figure.

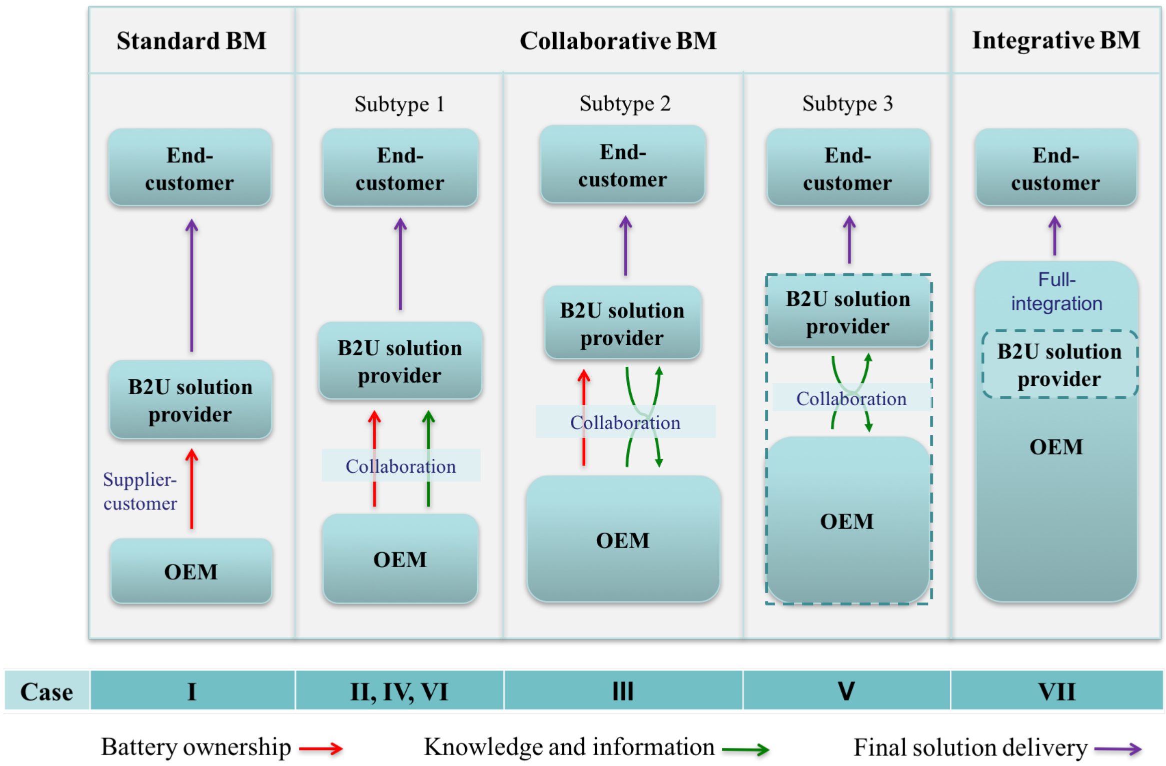

Figure 5.3 Schematic typology of B2U business models:

how cross-sector stakeholders interact to develop business models for second-life batteries

Standard business model

The standard BM is where the OEM simply sells second-life batteries to the B2U solution provider. The B2U solution provider develops the final solutions for the batteries and delivers that solution to the end-customers. A typical example of the standard BM is case I. The interaction between the OEM and the B2U solution provider is just a supplier-customer relationship, like in most BMs under the 'sell-and-disengage' logic. In that case, the OEMs involved in B2U can only gain some small additional revenues from selling the batteries in the free market. The OEM's degree of integration is nearly zero. They are not engaged in the final B2U solution development and there is almost no knowledge and information flow between the OEM and the B2U solution provider. This type of BM requires little OEM engagement but in the meantime, the value captured by the OEM is also small. The value in the information and data of the batteries is not captured by the OEMs. Instead, the B2U solution provider pays additional cost to understand and evaluate the battery characteristics, which could have been provided by the OEM. This standard BM is very vulnerable to competitors because they mainly compete in market price, which is susceptible to increasingly cheaper new batteries and second-life batteries with better information systems.

Collaborative business model

Most of the B2U firms developing B2U fall into the second type – collaborative BM. Under this type, the OEMs collaborate with B2U solution providers and are more or less involved in the final solution development. Instead of just selling the battery asset, OEMs under this BM type collaborate with B2U solution providers in different ways and to different extents, in order to add to the value of second-life batteries and capture more benefits than just selling the batteries. Three subtypes of collaborative BMs are generalised depending on the relative dominance of the final solution development between the OEM and B2U solution provider. The three subtypes are: a) assistant-collaborative where OEMs assist B2U solution providers in the final solution development; b) OEMs co-develop the final B2U solution with B2U solution providers; and c) B2U solution providers develop the final B2U solution for the OEMs. These subtypes are discussed in turn below.

Subtype 1. Assistant-collaborative – OEMs assist B2U solution providers in the final solution development

In this subtype, the final solution is still developed and delivered by the B2U solution provider and the OEM still sells the battery. Unlike the standard BM, however, the OEM also collaborates with the B2U solution provider to share knowledge and resources that contribute to the final solution development, in addition to selling the batteries. In case II and VI for example, the OEMs collaborate with the B2U solution providers to share their expertise and information on the batteries (e.g. battery historical data and remaining performance evaluation) to make second-life batteries better fit into the storage systems developed by the B2U solution providers. In case IV, the OEM provides consultancy services and tailor-made batteries to the B2U solution providers to help them better develop the final solutions.

In this subtype, the OEM's degree of integration is higher than that of the standard BM but is still very low. The B2U solution provider dominates the final solution development. The OEMs provide knowledge and information on the battery side to assist the B2U solution provider, but are not actually engaged in designing and delivering the final solutions. The value captured by the OEMs under this BM type is higher than the standard BM -- they can either sell the batteries at a higher price because they integrate some value-added activities (e.g. battery data and performance evaluation), or profit from providing additional services (e.g. consultancy), but it is still small because the OEMs do not directly capture the value from the final solutions delivered through the batteries.

Subtype 2. Co-development collaborative – OEMs co-develop the final solution with B2U solution providers

In this subtype, the final solution is co-developed by the OEM and the B2U solution provider, and the OEM still sells the batteries. Each stakeholder has its own set of knowledge and resources. Through the collaboration, the two stakeholders integrate complementary capabilities to design and optimise the battery systems, as well as develop the final products and solutions. The OEM's degree of integration here is higher than in subtype 1 because the

OEM is engaged in integrating the capabilities of the two parties to co-develop the final solution, in addition to selling batteries. There are bi-directional and interacting flows of knowledge and information between the two stakeholders because the final solutions are their mutual objectives and outcomes. The value captured by the OEM in this BM type is higher than the previous two BM types because the OEM benefits from co-developing the final solutions, in addition to selling the batteries. For instance, the OEMs have more flexibility in capturing the value from the final solutions. A typical example of this BM subtype can be found in case III in which the OEM is also involved in delivering the final solutions to the end-customers through their sales channel and shares the revenues from the final solutions with the B2U solution provider.

Subtype 3. Integration-collaborative – B2U solution providers develop the final solution for the OEMs

In this subtype, the OEM retains the ownership of the battery and works jointly with its partners (including the B2U solution provider) to develop and market the final solutions for them. Retaining the ownership of the batteries allows the OEM to continuously engage in B2U to extract value throughout the second life of the batteries. The degree of integration is higher than in the previous two subtypes because the OEM creates a joint venture where they 'exploit' the B2U solution provider to help them develop and deliver the final solutions to the end-customers. The OEM shares the revenue from the final solutions with the B2U solution provider. In this subtype the OEM dominates the final solution development. There are also bi-directional, interacting flows of knowledge and information between the two stakeholders to develop the final solution. The value captured by the OEM in this BM subtype is higher than the previous BMs because the OEM retains the battery ownership, which enables them to continuously optimise and extract value from second-life batteries. A typical example of this BM subtype can be found in case V.

Integrative business model

The integrative BM is where the OEM internalises B2U into their business, develops and delivers the final solutions to the end-customers. In this type, the OEM leverages its own networks to develop the final solutions and maximize the value that they can obtain from delivering that final product or service to the end-customers. A typical example of the integrative BM is case VII. The integrative BM requires very high OEM engagement and use of the diversified resources and capabilities of the company. The OEM's value capture portion is the highest among all the BM types because the OEM internalises the role of B2U solution provider which enables them to obtain all the potential value delivered by the final solution. However, depending on the OEM's capabilities in the energy market, some might be restricted to certain applications due to the OEM's limited access to certain energy markets (e.g. grid-scale applications).

In summary, a typology of current B2U business models is proposed. The typology compares existing B2U business models in practice to illustrate how automotive OEMs are interacting in different ways with stakeholders from the energy sector to create and capture value from second-life batteries. The standard and integrative BMs are the two extremes of the existing B2U business models. Evidence from the case studies show that the standard BM requires little OEM engagement but is very vulnerable to competitors. The integrative BM, on the other side, allows the OEM to capture more value from B2U than other BMs but might be restricted in terms of the range of applicable markets and applications. This typology is directly generated from the empirical data and is the first of its kind to show how B2U stakeholders are interacting in different ways to create and capture value from second-life batteries, which provides a fresh insight into the research area of BMs of B2U.

5.4 How are firms currently designing B2U business models?

As discussed above, in most cases, the automotive OEMs collaborate with stakeholders from the energy sector to create and capture value from B2U. Through various forms of partnerships, the OEMs share knowledge and resources that contribute to the final solutions for second-life batteries. It is found that there is a trend of shifting from the traditional 'sell-and-disengage' logic in the B2U business models examined. As noted in the previous section, instead of just selling the batteries, the OEMs are sharing information, knowledge and expertise on the battery side to add to the value of the final solution for second-life batteries. In one of the case studies (case IV), the OEM provided tailored battery systems and even consultancy on the battery applications as a service. In a broad sense, the service component of the BMs increases from left to right in the typology shown in Figure 5.3.

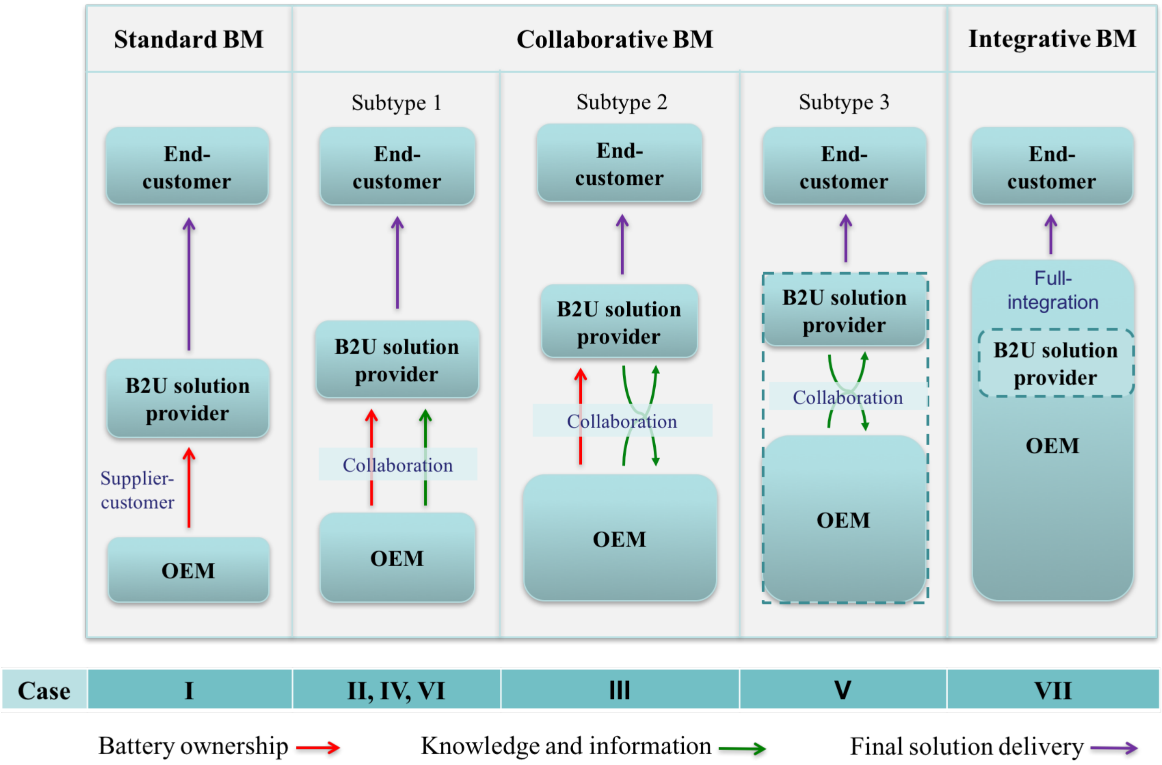

Figure 5.3. Schematic typology of B2U business models: how cross-sector stakeholders interact to develop business models for second-life batteries

In terms of providing the final B2U solutions to the end-customers (either by the B2U solution provider or the OEM), it can be seen from the data that the concept of service is present in all the seven case studies, regardless of how the OEM interacts with the B2U solution provider. The empirical data show that service is a prevalent concept in the value propositions of the final B2U solutions to the end-customers. In some case studies (case I, II and V), the B2U solution provider was offering energy storage as a service without selling any physical products. In other cases, in addition to selling the battery products, they provide various bundled services with the products, for example, installation, operation and maintenance to support the product offers.

The BM analysis of the seven case studies show that all of the phenomena described above have been part of the transition from selling second-life batteries as a product to providing energy storage as a service. The transition to service in the B2U business models is captured from the five underlying trends described by Neely et al. (2011), namely, the shift from products to solutions, outputs to outcomes, transactions to relationships, suppliers to network partners, elements to ecosystems. In most cases, the OEM's business model is still selling the batteries. But instead of just selling the physical asset through a supplier-customer relationship (e.g. case I), most of the OEMs also partner with the B2U solution provider, sharing knowledge and expertise that contribute to the final solutions for the batteries. In case V, the OEM even retained the ownership of the battery and only provided energy services to the end-customers.

In regards to the business models of the B2U solution providers, there is a clear trend toward solutions supplementing products, outcomes supplementing outputs, partner networks supplementing suppliers, and relationships supplementing transactions. The shift from elements to ecosystems is not clearly identified in the case studies. A possible reason is that B2U is at the ferment phase where the ecosystem elements are still in the early development phase or haven't emerged yet.

In the case of B2U, the three types of services from product firms described by Cusumano et al. (2015), namely, smoothing, adapting, and substituting services, were observed in all seven case studies. In terms of providing the final B2U solutions to the end-customers, the three types of services are present in different case studies. Case I, II and V are examples of the stakeholder substituting the battery product with various energy storage services (e.g. EV charging, energy management, and grid-related swarm storage services). Case III and VI are examples of the B2U solution provider offering adapting services. In case III, the B2U solution provider connects the end-customers with the electricity aggregators to participate in various grid-related services, which expands the functionality of the battery product and helps customers find new uses for the storage batteries. In case VI, the B2U solution provider remotely monitors the systems and offers end-to-end support through the energy storage specialists of the company in terms of installation, operation and maintenance services to help customers maximise the commercial value of the batteries. Case VII is an example of a firm smoothing the battery products by providing warranties, maintenance, technical support and so on.

The three types of services were not clearly identified in the OEM's business models since most of them are still adopting battery selling as their main BMs, although they collaborate with the B2U solution providers to share information and knowledge. However, Case IV is an exception where the OEM provides product adapting services. In addition to selling the batteries, the OEM provides consultancy services as well as customized battery systems to extend the value propositions of the batteries that expand the product functionality. In case I there is no service flow between the OEM and the B2U solution provider but there is a third party standing in between that provides logistic services to the OEM and battery testing and grading services to the B2U solution providers.

In summary, it can be seen from the data that there is a variety in the shifting to services in B2U business models, especially in the final battery solutions to the end-customers. In various forms, the B2U stakeholders are integrating services in their BMs to help support the battery product offers, extend product value propositions or to substitute the product altogether in the early stages of the B2U development. It is found from the data that compared with the 'sell-and-disengage' logic, integrating services into the BMs adds most to the value of second-life batteries and has the potential to help stakeholders capture more value from B2U (discussed in detail in Chapter 6).

5.5 What are the factors that influence B2U business model selection?

In the light of the previous discussion on the existing B2U business model types (Section 5.3), we can now ask the question what are the factors that influence B2U business model selection? The data from the seven case studies show that the automotive OEMs are adopting differentiated business models for B2U, even within the firm (e.g. case I, II and III). In the nascent stage of B2U, there is a high level of uncertainty regarding the battery technology and the market of second-life batteries. Although the concept of B2U is not new to the industry, it is unclear to both the OEMs and customers how second-life batteries will perform, what functions they will deliver and how to best realize the value of the batteries. In this early phase, the automotive OEMs are experimenting with different BMs in various markets to search for the best possible solutions. Based on the BM analysis in the seven case studies, this section aims to compare across cases to understand the factors that might influence the BM selection for the OEMs in the early phases of B2U.

The data suggest that in case I, the OEM selected the standard BM – battery selling because the application, mobile EV charging service is a niche application promoted by a small start-up, which is "*of lower priority*" for the OEM (BJV-1). The alignment of interests between the OEM and the B2U solution provider is very low. For the OEM, their purpose is just to generate additional revenues through selling the battery asset at a very cheap price. The OEM is not involved in the final solution development and there is no sharing of knowledge and resources between the OEM and the B2U solution provider.

In case II, III, IV, V and VI, the OEMs selected collaborative BMs. Instead of just selling the batteries, the OEMs also collaborated with the energy stakeholders in various forms. In case II, IV and VI, the OEMs selected assistant-collaborative BMs where they collaborated with their energy storage partners in the setup of the battery system. The OEMs were trying to fit the batteries into the systems developed by the energy stakeholder, in addition to selling the batteries. For the OEMs, their main purpose is to sell the batteries and get additional revenues, but at the meantime they also want to make the batteries more valuable by sharing their knowledge and information on the battery side. The alignment of interests between the two stakeholders is higher than that in standard BMs because the OEMs also want to contribute towards the final B2U solutions through the collaboration.

In case III, the OEM co-developed the final solution with the energy stakeholder for the residential application. The two stakeholders have very complementary knowledge and capabilities. They also have higher alignment of interests than in the previous BMs because the OEM is also involved in the final solution development through collaboration. For the OEM, the purpose is to add to the value of the final solution in addition to selling the batteries.

In case V, the OEM selected integrative-collaborative BMs. They do not have the knowledge and resources in grid-related energy storage so they exploited the energy stakeholder to help them develop the final solution. By retaining the ownership of the battery, the OEM wants to maximise the battery value and also captures more value from it. The purpose of their BM is not to profit from selling the physical product, but to optimise the value of the battery and continuously benefit from grid-related energy services delivered through the batteries.

In case VII, the OEM developed the final solutions by vertically integrating the resources and capabilities of its own networks. The purpose of their BM is to "*use it more to generate more value*" by providing the final solutions all by themselves (O-4).

It can be seen from the data that the OEMs are not selecting B2U business models based on one single force. Rather, the BMs are selected depending on a complex mixture of interrelated factors. It can be seen from the above analysis that the alignment of interests between the OEM and B2U solution provider influence the OEM's B2U business model selection.

When the alignment of interests between the two key stakeholders is very low (e.g. the OEM is completely not involved in the final solution development), the OEM tends to select standard BMs to just sell the batteries. As the alignment of interests between the two stakeholders increases (e.g. the OEM intends to help with the setup of the final solution and capture some value from it), the OEM is more likely to select assistant-collaborative BMs. And the OEM tends to select co-development collaborative BMs when their interests align at a higher degree with the B2U solution provider (e.g. the OEMs intends to be involved in the design and development of the final solution and capture more value from it). When the alignment of interests between the two stakeholders further increases (e.g. the OEM intends to continuously benefit from delivering the final solution and share the revenue with the B2U solution provider), the OEM tends to select integrative-collaborative BMs. When the OEM internalises the role of B2U solution provider where the alignment of interests could be regarded as the highest, the OEM tends to select integrative BMs to obtain the most benefits from the batteries.

The purposes of B2U for the OEMs also influence their BM selection. When the OEM just wants to sell the batteries to gain some additional revenues without investing in B2U, they tend to select standard BMs because they do not need to innovate a lot. It is more likely that the OEMs select integrative-collaborative or integrative BMs if they want to maximise the value of the batteries. The data suggest that with the purpose of B2U changing gradually from obtaining additional revenues to maximising the value of second-life batteries, the OEM's degree of integrating B2U into their businesses increases and the BM selection tends to change from standard, to collaborative and to integrative BMs accordingly.

The second use applications of the batteries might also have an influence on the BM selection because different applications require different sets of knowledge, resources and capabilities. However, there is no clear pattern identified from the seven case studies. A possible reason is that currently OEMs are experimenting with various B2U applications to test their BMs. As the B2U business model matures, future research should investigate the pattern of, for example, what types of BMs fit what kind of B2U applications, so as to better help practitioners with their BM selection.

The data suggest that internally, the purpose of B2U as well as the alignment of interests between the OEMs and B2U solution providers are two factors influencing the OEM's B2U business model selection. The effects of the two factors against the B2U business model typology is shown in Figure 5.4. As shown in the figure, with the main purpose of B2U gradually transferring from obtaining additional revenues to maximising the value of second-life batteries, coupled with the alignment of interests between the OEM and B2U solution provider increasing to the maximum, the BMs tend to change from standard, to assistant-collaborative, to co-development collaborative, to integrative-collaborative and finally to integrative BMs.

In the currently nascent stage of B2U, there are no established business models for B2U. Emerging factors might continuously influence how OEMs select business models for B2U. Some external factors, such as the decreasing cost of new batteries, are also changing how OEMs think about B2U. For example, one of the interviewees commented: "*Some of our initial thinking might have been built directly into the market as a candidate system to compete with any new battery systems, but as new battery cost comes down so dramatically… some of our views on how to make it into the market have changed.*" It is changing the way the OEM arranges its business around B2U: "*It might be in partnership with Company E for example, as opposed to us doing it independently. But it also might be that we do something that looks like Company E as opposed to selling it. Nothing is chosen under the stone at the moment*" (O-1-2). The data suggest that apart from the decreasing cost of new batteries, the regulations and market conditions of energy storage are also shaping the way OEMs select their B2U business models.

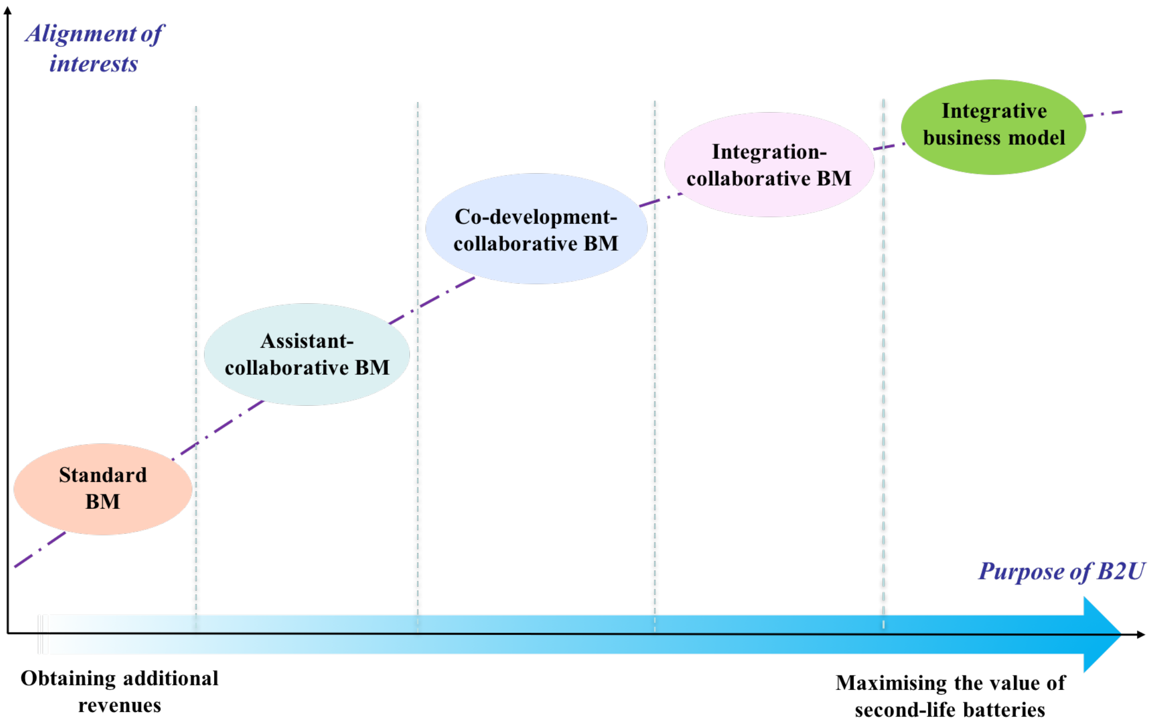

Figure 5.4 How purpose and alignment of interests influence B2U business model selection

5.6 Summary

In summary, this chapter presents the cross-case findings of the seven case studies through answering the five key questions posed. The motivations and benefits of B2U were first compared across the seven cases, followed by a comprehensive analysis of the four dimensions of the critical B2U challenges, namely, competitiveness, uncertainty, design and regulations. A typology of current B2U business models was then proposed to compare the findings across cases and generalize how OEMs are currently creating and capturing value from second-life batteries. Through examining how B2U stakeholders are designing business models for B2U, it was found in the case studies that there is a variety of shifting to services in their BMs. The purposes of B2U as well as the alignment of interests between the OEM and B2U solution provider are influencing the BM selection for the OEMs. The applications of second-life batteries might also influence how the OEMs select BMs. External factors such as new battery price, regulations and energy market conditions are also shaping the way OEMs think about B2U. The findings in relation to the existing knowledge is discussed in the next chapter.

6 Synthesis and Discussion

This chapter reflects on the implications of the cross-case findings and presents further synthesis and new findings. A final framework is also proposed to illustrate the key points made in this research. Furthermore, it discusses the findings in relation to existing knowledge and implications for practice.

6.1 What is the role of business models in B2U?

The critical challenges confronted by B2U stakeholders were discussed in Section 5.2. Many of the challenges mentioned are still perceived as operating under the ‘business-as-usual’ scenario with the traditional product selling model. Offering the repurposed battery as a discounted product (compared with new batteries) is pushing the ‘inferior’ second-life batteries into increasingly fierce competition with new batteries, which might impair the realization of the potential value of the battery and is argued to be not sustainable. Under the ‘sell-and-disengage’ logic, the only way for second-life batteries to compete is to lower the price continuously in line with the decreasing cost of new batteries. The reward from selling the battery asset is thus very low. And one day when the cost advantage of second-life batteries becomes negligible, the ‘inferior’ aged batteries could be driven out of the market. The data from the seven case studies suggest that the ‘sell-and-disengage’ model is not helping stakeholders achieve the potential value of second-life batteries in energy storage.

To realize the potential benefits that can be delivered from B2U, a new way of perceiving the value of second-life batteries as more than a physical product is needed. As one of the interviewees commented:

> “*One important thing to keep in mind is that it (B2U) doesn’t diminish the utility of the battery, the battery is just as good as any energy storage device. And regardless of what the price point is comparatively, it still has a good function and capability. It is, how can you create a structure that makes it worthwhile to pursue that matters*” (O-1-2).

Though somewhat degraded in terms of capacity, the value of the storage capacity of second-life batteries should not be discounted. When applied in certain applications, a second-life battery could deliver just the same functions and services as a new one. The key is to best utilise the remaining capacity of second-life batteries in the right energy storage applications to generate value.

However, a second-life battery itself does not have a value proposition, it is the BM that creates value for second-life batteries and helps stakeholders capture the benefits. BMs and the logic of value exchange was a constant part of the case study interviews even when speaking to the technical people. One of the interviewees, for example, emphasized the importance of a good BM on B2U: "*A good business model is the key so the customer can pleasingly accept the storage system*" (BJV-1). In some cases, customers do not care whether the battery is new or old, they only value the power or capacity services delivered through the batteries. As captured in the following quotes: *"A battery doesn't do anything – it is what you build around the battery to solve what pain points for your customers. Our customers don't care whether you use second-life batteries, as long as it does what they tell us to do*" (E-1).

The shifting to services in the B2U business models was discussed in Section 5.4. The data suggest that the 'inferiority' of second-life batteries could be overcome by delivering the solutions customers want rather than selling the physical asset. In that case, what matters most is not how technologically advanced the battery itself is, but the value of the solutions delivered by the battery through the BMs. The value that stakeholders capture from delivering that solutions could also be increased because they can continuously engage in and benefit from the various services provided through the battery rather than the one-off product selling.

In summary, due to the nature of second-life batteries, which is a used product, the BM plays a pivotal role in achieving the potential value of the batteries. The data indicate that a good BM has dual functions: to help address the challenges of B2U to overcome the 'inferiority' of second-life batteries as used products; and to help stakeholders better create and capture value from delivering solutions for second-life batteries. The importance of innovative business models in B2U derived from the empirical data addressed in this study provides new insights for achieving the potential value of second-life batteries.

6.2 How can firms better design business models to achieve the potential value of second-life batteries?

This section synthesises the emerging findings that help bring the researcher closer to the answer of the main research question. Three critical BM design elements, namely, life cycle thinking, system-level thinking and the shift to services are proposed as helpful aspects to help B2U firms better achieve the potential value of second-life batteries. The three aspects are discussed in turn below.

6.2.1 Life cycle thinking for analysing the potential value of second-life batteries

In the light of the earlier discussion of the critical challenges of B2U (Section 5.2) that might impair the real value of second-life batteries, we can now ask the question what is the practitioners' understanding of the potential value of second-life batteries? At the nascent stage of B2U, the value of second-life batteries is still poorly understood and B2U firms are not very good at extracting value from second-life batteries. All seven case studies show that there are more B2U benefits available that the firms are not fully accessing. Across the data, it is found that value opportunities existed in various stages of the battery life cycle. In this section, a battery life cycle thinking perspective is proposed to help analyse the potential value of second-life batteries and identify opportunities for improved value creation along the battery life cycle.

Second-life batteries, by definition, are 'inferior' to new batteries in terms of performance, lifetime and functionalities for some specific applications. However, the potential value of second-life batteries could be as high as, or even higher than that of a new battery if equipped with a good BM. At this emerging stage of B2U, it is important that stakeholders understand the potential value of second-life batteries so as to identify value opportunities and better design BMs for increased value creation. Based on the BM analysis of the seven case studies, it is found that a life cycle thinking which integrates the battery's first life in EVs, second-life in storage applications and end-of-life (EOL), is helpful to understand the value created for various stakeholders and potential value opportunities along the entire battery life cycle.

Unlike new batteries designed for stationary storage, the data show that a second-life battery involves multiple stakeholders at various stages of its life cycle. B2U itself is considered as an EOL strategy for EV batteries, as well as a circular approach to creating value from 'waste'. However, repurposing a second-life for the batteries also means that those once retired batteries will start a new life cycle in a different application. For second-life batteries, the battery conditions depend on how they were designed and used during their first life in the vehicles. In other words, the battery's first life in the EVs partially determines the performance and residual value of the batteries during their second life. On the other hand, the value analysis should also include the final EOL when the batteries could not be utilised anymore, for example, the value of recycling.

Therefore, analysis of the second-life battery value should be embedded in considering its entire life cycle in a broader sense that includes multiple lives: a) the first life in the EVs, b) the second life in, for example, stationary storage applications and c) the EOL when the batteries are recycled or disposed. The key stages of the battery life cycle are illustrated in Figure 6.1 to help analyse how second-life battery value could be improved by considering the entire battery life cycle.

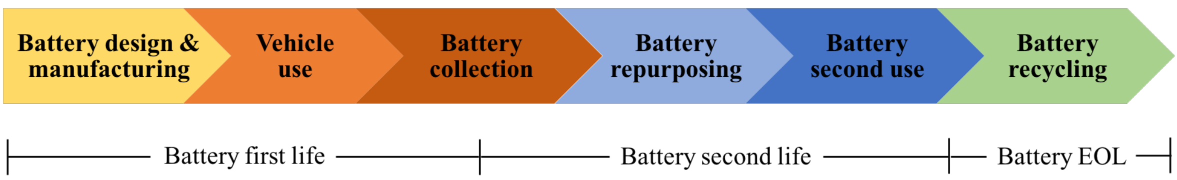

Figure 6.1 Key stages of the life cycle thinking for analysing the value of second-life batteries

Battery first life

As shown in Figure 6.1, the battery first life includes battery design and manufacturing, vehicle use and battery return for collection. The battery is designed and manufactured for the EVs by the automotive OEMs and/or battery producers. Then the batteries are used as the vehicle traction by the EV customers. After the battery could not satisfy EV drivers' demands such as driving range, acceleration and charging rate, the batteries will retire from EVs. The initial status and thus, the remaining value of the second-life batteries depends on how they were initially designed and used during their first life. The data indicate that three aspects of the battery first life, namely, initial battery design, EV battery ownership and education for consumers, should be considered to facilitate B2U and increase the battery residual value.

Initial battery design

As discussed in the previous section, incorporating B2U into the initial EV battery design through, for example, better data tracking and collection system, improved reusability and durability of the battery pack components, could greatly reduce the battery repurposing cost and smoothe the process of B2U.

EV battery ownership

The second aspect is the EV business models regarding battery ownership. One of the challenges discussed is the management of the second-life battery flow. In most cases, once the OEMs sell the EVs they do not have ownership of the batteries anymore. They might have the liability for battery recycling depending on regions but they actually have little control over the battery flow in terms of when or where the retired batteries will come back, for example. Interestingly, in one of the case studies (case VI) where 80 to 90% of the EV batteries are under the leasing model, the OEM remains the owner of the battery and thus have much more control over the volume and quality of the batteries coming back. In addition, because the OEM owns the battery property, they can provide various maintenance services to the EV customers to keep the battery running under the best possible conditions. When the battery capacity drops to a certain level, the OEM swaps the batteries and keep the old ones for repurposing or recycling depending on the battery conditions. In that case, the battery quality is also more unified which enables more efficient and profitable B2U.

Education for the consumers

The third aspect of improving the residual value of second-life batteries is to educate the EV customers on better utilizing the batteries. OEMs could give advice to the EV drivers in terms of how to take care of the batteries during EV driving and help them understand the value of their batteries after the vehicle life. Rewarding mechanisms could also be built for example, where customers get a better price if they return batteries with higher quality. Besides, the OEMs could offer maintenance services on a regular basis to check the batteries and repair any degraded components if necessary to avoid further deterioration of the batteries. In that case, the customer relationship is strengthened which also brings value for the OEMs in terms of more valuable EV offerings for the customers.

Battery second life

As shown in Figure 6.1, the battery second life includes battery collection, repurposing (e.g. testing, grading, system integration) and second use in various energy storage applications. After the batteries are retired from the EVs, the automotive OEMs collect the batteries through their car dealers, test them and decide whether to repurpose or recycle them. For batteries that could be further utilized, they will be graded according to their remaining capacity, and then sorted and repackaged. Depending on the applications, the batteries are integrated to build the energy storage systems by the automotive OEMs and/or the energy companies. The storage system composed of second-life batteries are then sold to the customers in the energy market or operated to provide various energy services. Since the batteries are repurposed for a different application (energy storage) rather than in the automotive industry, multiple stakeholders across sectors might be involved at different stages and it is essential to coordinate among stakeholders to improve the cost structure and improve the total value creation. The data suggest that three aspects of the battery second-life, namely, battery redemption, battery repurposing strategies, as well as battery testing and grading should be taken into consideration to increase the value of second-life batteries.

Battery redemption

In terms of battery collection, there is currently no established mechanism of the battery return flow. In some regions like China and Europe, it is stated in the Extended Producer Responsibility (EPR) that OEMs are responsible for retired EV batteries. However, this doesn't mean that EV owners are forced to return their retired batteries to OEMs because it is the customer’s property (except the EV leasing model). When the market for second-life batteries takes off, it would be difficult for OEMs to collect the retired batteries from EV owners for free. For the time being, most of the retired EV batteries collected by the OEMs come from their vehicle testing fleets. In the future, OEMs need to establish their battery collection system and incentive mechanisms to obtain second-life batteries.

Currently, some of the retired batteries are collected through the OEM’s dealerships. When EV customers return the old batteries to the car dealers, they send all the batteries, good or bad, back to the OEMs. Interestingly, in one of the case studies (case VII) the interviewees proposed a fast testing plan in which the batteries are tested at the dealers to quickly check their conditions before shipping them out. Only the batteries qualified for further second-life utilization will be transported to the OEMs while the bad quality ones will be sent directly for recycling, which helps save cost in battery transportation. In another case study (case I), the OEM outsourced a third party to do the logistics who collect the batteries for them from their car dealers. The OEMs need to weigh the cost of battery collection against their specific situations to decide a most cost-efficient plan.

Battery repurposing strategies

Based on the seven case studies, the data show that there are generally two different battery repurposing strategies: 1) to disassemble the battery pack into modules and repackage the modules, and 2) to reuse the whole battery pack as it is. According to the case studies conducted, both strategies are used by different OEMs in practice. Most of the OEMs adopt the latter strategy to reuse the whole battery pack in that the costs regarding opening the battery pack, testing individual modules and repackaging can be avoided. In addition, key components such as the BMS and cooling functions could also be reused to avoid additional cost. However, some of the OEMs insist that reassembling the modules of similar conditions could extend the lifetime of the battery and thus increase their residual value. Currently, there is no consensus on which strategy is more economically viable but both will require the incorporation of second use into the initial battery design. For example, if you want to disassemble the battery pack into modules for second use, the battery should be designed for easy disassembling. On the other hand, if you want to reuse the pack as it is in stationary storage applications, you need to ensure the reusability and durability of the battery components needed for second-life applications so that they could also be reused as a whole in a more sustainable way.

Battery testing and grading

The batteries are then tested, graded and sorted for different second-life applications. In some cases, battery testing and grading are done by external parties which incur extra costs. How much the cost can be internalized depends on how much efforts the OEMs make in tracking the battery data during its first life in EVs and being able to analyse that data. Depending on the capacity remaining, the batteries are then graded and sorted for different storage applications. However, knowledge in energy storage is also required to determine what is the best usage profile for each battery to better utilize the battery value. In most cases, the OEMs bring in partners from the energy sector to develop or assist them in designing the final solutions to commercialise the batteries in the right energy market.

Battery EOL

Depending on the battery conditions after its first life and its usage profiles during second life, second-life batteries could be further used in stationary storage applications. After that when the batteries could not be further utilised, they will be recycled or disposed. Currently, the recycling system for EV batteries is not established yet, so the cost of recycling could be quite high in the near term. The case studies indicate that battery recycling incurs cost nowadays but it is possible that in the future, recycling will bring profits instead of incurring expenses. Through deploying second-life batteries in stationary storage applications for another 5 or 10 years, for example, the OEMs could defer the recycling phase and turn the cost into revenue opportunities. As one of the OEM said: "*This (recycling) is important to follow up because recycling cost will always change. Today there might be a cost to it, tomorrow it might be a benefit*" (O-3). In B2U, the stakeholders should also make clear the battery recycling responsibilities for the very end of the battery life.

In summary, thinking about B2U from the life cycle perspective is helpful in analysing and revealing the potential value of second-life batteries and to identify opportunities for increased value creation. At the emerging stage of B2U, it is essential that stakeholders understand the potential value of second-life batteries at this system level so as to better design their BMs to achieve that value. Life cycle thinking helps integrate resources and knowledge from cross-sector stakeholders to improve the cost structure over the entire battery value chain.

6.2.2 System-level design for achieving the potential value of second-life batteries

The concept 'activity system of second-life batteries' was introduced in Section 3.5 as the level of analysis for this study. The author proposes that it helps analyse, at the system level, how the value of second-life batteries is created through a series of activities conducted by key stakeholders that transform the retired batteries into the final solutions for the end-customers. The value of second-life batteries in energy storage is delivered to the end-customers either in the form of the battery products or the services provided by the storage systems. How to best utilize the value of the batteries requires the integration of knowledge and expertise from both the automotive and energy sectors, as well as a good BM that helps deliver that value to various stakeholders involved. The BM analysis in the seven case studies show that the system-level design which transcends the firm's boundary is helpful to analyse the total value creation for second-life batteries. This section aims to present how system-level design could help achieve the potential value of second-life batteries.

It can be seen from the data that if the OEM only looks at the benefits of B2U from the firm perspective, the perceived value of second-life batteries is segmented because the full potential value of the battery is not realized until the final battery solution is delivered to the end-customers. From the OEM's perspective, for example, in cases where they sell the batteries, the value of second-life batteries for them is just the sales of the battery asset. However, there are many more available benefits delivered through the batteries, for example, the value of various energy services, that the OEMs are not accessing. The system-level design is helpful for the B2U stakeholders to analyse the full potential value of the batteries, identify value opportunities and design BMs to better achieve that value.

On the other hand, thinking about B2U only from the firm perspective is not helping to extract the potential value from second-life batteries. The data show that under the 'sell-and-disengage' logic, some of the systems are badly designed and they are fragile. In that case, people just want to sell the batteries to obtain additional revenues without trying to improve the value system. They seem to work for a period of time when they can predict second-life battery price is lower than new batteries, but they are not a sustainable BM in the medium to long term because other things are changing. For example, one of the interviewees of Company B complained:

> "*If we can't get a warranty then we will stop using Company A's second-life batteries… In order to scale up, we need to be 100% certain that Company A is going to keep providing us batteries, but I can't be sure about that, not today…If the OEMs are too difficult to work with, then we will simply move to other suppliers… and because battery price is falling so quickly, we think in the long run our main suppliers would be new battery manufacturers*" (E-1).

When Company B is small and only doing business on a small scale, it's not so concerned about the transparency of the supply schedule but if they want to scale, they have to be sure about the battery supply and they need proper contracts and warranties. However, the OEM (Company A) in this case is not helping make the life easier for Company B. They are not concerned about how Company B creates value for second-life batteries and they are not helping to improve the total value creation for the batteries. The consequence of that is their reward from B2U is very small and their BM is very vulnerable to competitors.

At the system level, the total value creation for second-life batteries determines the 'overall size of the value pie', which is also the upper limit of the value that stakeholders can capture from. The data suggest that if one is only trying to create and capture value from the firm perspective, they are partially optimising the value without increasing the 'overall size of the value pie'. In order to increase the total value creation for the batteries and thus their value capture potential, stakeholders should also consider the value creation of other players and design BMs that facilitate value creation for the whole value system. The system-level design that considers value creation and capture of multiple stakeholders as well as the synergies between them could help stakeholders better understand how to increase the system-level value creation for second-life batteries to enlarge the 'value pie'.

In summary, the system-level design is helpful for stakeholders to analyse the potential value of second-life batteries and identify value opportunities to realize that potential value. It could also help stakeholders increase the total value creation for the batteries and thus increase the 'overall size of the value pie'. B2U stakeholders should take the system perspective into their BM design to enlarge the 'value pie' so as to achieve the potential value of the batteries and enable more value capture for themselves.

6.2.3 Shift to services

As discussed in Section 6.1, BM is a key to overcoming the B2U challenges and achieving the potential value of second-life batteries. The data suggest that the traditional ‘sell-and-disengage’ logic is no longer suitable for B2U and a shift to services has been observed in all seven case studies. This section further synthesises the previous findings and discusses how the concept of service could help achieve the battery value and how stakeholders could better integrate this concept into their BMs.

The three types of services (smoothing, adapting, and substituting services) identified in the existing B2U business models have been discussed in Section 5.4. In terms of providing the final battery solutions to the end-customers, the BM analysis show that in most cases, the B2U solution providers are offering substituting or adapting services that either extend the value propositions of the battery or replace the purchase of a product altogether. The interview data suggest that integrating services into the BMs changes the perceived value of second-life batteries. Interestingly, in three out of seven cases, the B2U solution providers are offering energy storage as a service without selling any physical products. Customers in these cases are not so concerned about how good the battery is and they are not comparing the prices because they do not own the battery asset. What matters to them is the energy storage solutions and the value of the services provided through the batteries. For example, one of the interviewees in Case I commented: “*Our customers don't care whether you use Company A’s old batteries, as long as it does what they tell us to do*” (E-1). One of the interviewees in Case II also said: “*Customers won’t care that it’s used batteries because they can get more savings. In our case, it becomes our risk where we own the asset*” (E-2). The data suggest that offering substituting services allows companies to take full advantage of the remaining value of the batteries to design differentiated value propositions that satisfy customers’ demands in energy storage. Furthermore, it reduces the risks on the customers, which makes it easier and faster to enter the market. It proves to be useful, especially in the ferment stages of B2U when customers are not familiar with the technology and feel unsecured about used products.

In terms of the OEM’s business model, the data show that apart from case V and VII where the OEMs retain the battery ownership, in all the other five cases the OEMs are selling the batteries to the B2U solution providers. Most of them provide smoothing services such as warranties and technical support that complement their battery offers. They are not separately providing and benefiting from the services but they obtain higher revenues from selling the more 'premium' battery product compared with the pure selling model. In case III, the consultancy service is also an important part of the OEM's value proposition. The OEM profits from providing consultancy services apart from selling the batteries. In those cases, the OEMs benefit more or less from providing services in different forms. However, they are still selling the batteries and once they sell the batteries they stop profiting from the potential value of the various energy services provided by the batteries. In case V, the OEM retains the ownership of the battery and bring the batteries into the joint venture. The B2U solution provider is providing services to the OEM to help them develop and deliver the final solutions to the end-customers. The OEM shares the revenues from the energy services provided by the batteries and they are able to continuously capture value from the batteries during the entire life of the battery.

The data suggest that integrating the concept of service could help OEMs generate more value from B2U than the traditional selling model. If the main value proposition for the OEM is the sales of the battery, there are various transaction costs involved and the OEM also fails to profit from the potential value of the energy services provided through the batteries. As commented by one of the interviewees: "*If OEMs sell the battery they are in huge competition because there will always be someone who sells cheaper. As the most valuable asset, it doesn't make sense for OEMs to sell the battery*" (E-4). With new battery price decreasing rapidly, the traditional selling model would put OEMs in increasingly fierce competition in the battery market. The interviewee continued: "*As an OEM, you know the value, how long the battery can last and so on…they should provide the battery and they also know the battery best. If they sell the battery, the customers ask for warranty for several years and so on and these are all the cost factors that you pay for*" (E-4).

In summary, in the nascent phase of B2U, there is no established market for second-life batteries. B2U stakeholders are still exploring how to approach potential customers – whether to just sell the batteries, or to add some services to the battery offers, or to just offer services. The findings from this research suggest that in this early fermenting stage of the industry characterised by high uncertainties for both the supplier and customer, B2U stakeholders could either provide complementary services on top of selling the batteries or retain the ownership of the battery to reduce risks for their customers. Moreover, providing energy storage as a service instead of selling the physical product enables stakeholders to differentiate their value propositions and overcome the perceived 'inferiority' of second-life batteries as a 'used product'. Result-oriented services thus lead to opportunities for B2U stakeholders to innovate their BMs for second-life batteries.

6.3 Business Model of a Technology: A new perspective for understanding the value potential of second-life batteries

This section reflects the synthesis findings and proposes a new perspective, Business Model of a Technology (BMoT), for understanding how value is created, delivered and captured around and through second-life batteries at the system level. It should be noted that BMoT is not another definition of BM, but a system-level perspective for thinking about how to maximize the value of a technology. It is from the perspective of the technology itself – how we can predict the value potential of a technology, how to analyse that potential value and how stakeholders can better generate and capture value through the lens of BMs at the system level to enlarge the overall size of the value pie, so as to obtain bigger benefits from the technology. The focus of this study is to understand how the potential value from second-life batteries could be extracted, instead of how value are created and captured for a certain firm. BMoT is not restricted to a firm, it could be any stakeholders that are creating value for second-life batteries. And in most cases, it is the joint effort from multiple stakeholders with a set of interacting BMs. In this study, BMoT is defined as the set of value exchanges between multiple stakeholders that follow the technology from the start to the end of its life including its multiple use lives.

In Chapter 3, the analytical framework was introduced to help analyse the BMs at the system level. It was found from the case studies that discussions on BMs, especially with automotive

OEMs, reveal limited respondents who could offer up innovative BM ideas that help extract the potential value from second-life batteries. Most of them were able to discuss challenges to their current BMs by referring to specific dimensions of their BM that were challenged, but they were unable to offer solutions that help improve the value of second-life batteries. One of the reasons is that they lack the resources and capabilities in the energy storage industry. In order to better extract the potential value from second-life batteries, we need to look beyond a certain firm's BM to investigate how cross-sector stakeholders interact to develop their BMs.

The traditional thinking about BMs (firm-centric BMs) is very useful in understanding how a firm creates and captures value from delivering certain products or services, but is not as helpful as expected in this study. One of the reasons is that the technology (the second-life battery in this study), hasn't changed, but the ownership has changed. And although the technology hasn't changed, its performance has degraded and as a result, they would be used in different applications which would involve different market players and customers. When trying to understand how the potential value from second-life batteries could be extracted based on traditional thinking and writing (the existing literature) about BMs, it was found difficult to describe using the traditional BM language which takes a focal-firm perspective. As shown in most of the case studies, when talking about the BM of a certain company that is repurposing second-life batteries, it always involves BMs of another one or more companies because the batteries experience different stages of ownership before they reach the end-customers.

If the car manufacturer has the ownership of second-life batteries over their entire lifetime, then it is the BM of that car manufacturer that we should look into. However, the real case is more complex. The data show that the change of ownership and applications means it is much more difficult for OEMs or energy companies on their own to extract value from second-life batteries. To achieve the potential value of second-life batteries, we need to understand at the system level, how stakeholders interact to try to maximise the value potential of second-life batteries, and thus capture a bigger portion of that value.

BMoT is presented here as a useful perspective that helps understand the total value creation from second-life batteries. The potential value of second-life batteries depends on various stages of B2U where multiple stakeholders are involved. Second-life batteries are initially designed for EVs and used under different conditions by the EV owners for 8 to 10 years. Due to the complex nature of second-life batteries, which is a 'used product', the value of the battery is dependent on multiple stakeholders such as the OEMs, EV owners, and energy companies. Since B2U involves multiple stakeholders during various B2U stages, the potential value of the batteries depends on how stakeholders design their BMs not only to help themselves create and capture value, but also increase the total value creation for the batteries at the system level.

To improve the value of second-life batteries and thus extract more value from it, B2U stakeholders need to enlarge the overall size of the value pie. In that sense, the firm-centric perspective of BM in most cases is only partially optimising the value creation and capture for the firm itself and is thus limited in enlarging the 'upper limit' of the value they can capture from second-life batteries.

The BMoT perspective is technology-centric – how and what value could be created out of the technology. For different customer segments there will be different value propositions that second-life batteries might be able to provide and B2U stakeholders will need to build the necessary resources and capabilities to deliver the various value propositions through the technology to different customers. It could be the BM of a car manufacturer, it could be the BM of a battery recycling company, it could be the BM of an energy company, or it could even be the BM of the government. And in most cases, it is the stakeholders across different sectors that co-determine the value generation mechanism. You are not choosing/targeting customers, instead you look at what customers' needs are and how the technology could satisfy those needs. You are not evaluating and leveraging your own resources and capabilities, instead you look at what resources, capabilities and networks are needed in order to maximize the value of the technology. It is to break the boundaries of the focal firm and bring various stakeholders together to maximize the value of the technology. And the value is not restricted to economic benefits, but also includes social and environmental value.

In summary, BMoT provides a new perspective for analysing BMs at the system level: it is concerned with the total value creation and value capture from a certain technology over its entire life cycle for multiple stakeholders. The author suggests being more flexible about the perspective and level of BM analysis – firm, network, industry or technology. BMoT is useful in situations where we want to improve the value generation through a specific (especially new) technology which involves cross-sector stakeholders with multiple sites of ownership.

6.4 Building the framework

Based on the case study findings, a final framework (Figure 6.2) is proposed to present the key points made in this research:

- A typology of current B2U business models is helpful in understanding how B2U firms in practice are interacting in different ways to create and capture value from second-life batteries;
- Three critical BM design elements informed by existing B2U business models and key sustainability concepts are useful in designing BMs that help B2U firms better extract value from second-life batteries;
- The new perspective BMoT is helpful to understand the value potential of second-life batteries at the system level and serves two functions: a) overcoming critical challenges in extracting the value from second-life batteries; and b) enabling stakeholders to create and capture value from second-life batteries, which ultimately contribute to achieving the potential value of second-life batteries.

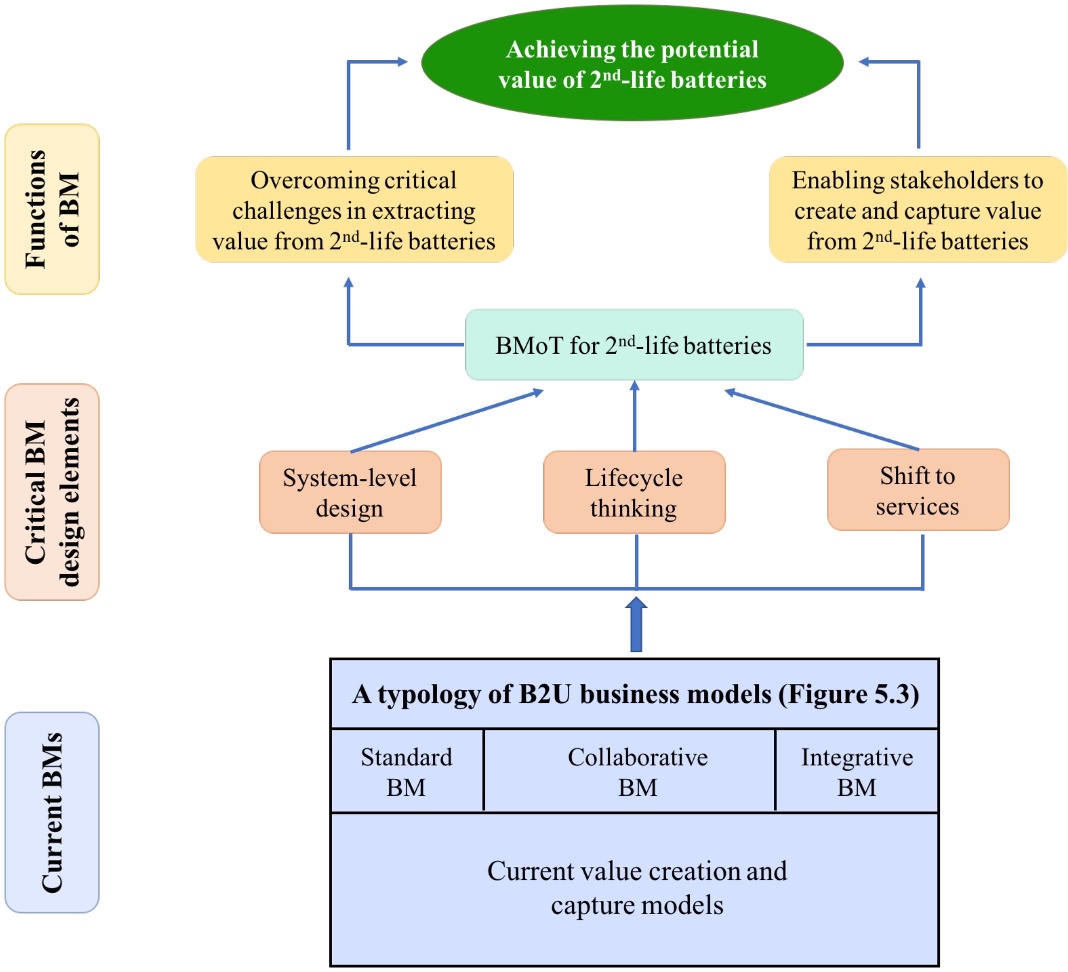

Figure 6.2 Final framework: business models of second-life batteries

This framework is developed based on findings from rich empirical data collected from B2U stakeholders across the automotive and energy sectors. It shows the logic of how the author answers the research questions: through analysing existing value creation and capture mechanisms via current B2U business model cases, critical BM design elements were drawn that help understand the value potential of second-life batteries and how to better extract the value. These contribute to the new perspective BMoT and help understand how BMs that draw on key sustainability concepts could overcome critical challenges and achieve the potential value of second-life batteries.

6.5 Findings in relation to existing knowledge

The literature shows a lack of research on B2U business models that draw on sustainability concepts to investigate the value potential of B2U and how to better extract value from second-life batteries. The results of the study filled this research gap and contributed to existing knowledge. This section discusses the findings in relation to that existing knowledge.

6.5.1 Sustainable value of second-life batteries – a comprehensive view of the potential B2U value

The benefits of B2U have been extensively discussed in the literature. However, most of the existing studies simply analyse the benefits of B2U in terms of economic or environmental feasibilities in a fixed number of assumed scenarios with little empirical evidence. Neubauer et al. (2015) indicated that the environmental and social benefits of B2U could be enormous, but then identified a need for further research. In this thesis, the author believes that the lack of a comprehensive view of the B2U benefits could lead to underestimated value of second-life batteries and jeopardise potential value opportunities.

Based on empirical data, this study has analysed the economic, social and environmental value for various stakeholders involved in B2U, which presents a significantly more comprehensive picture of the overall benefits of B2U from sustainable perspectives. In each case study, the economic, environmental and social value has been analysed for multiple stakeholders in different stages of the battery life cycle. The empirically-generated results show multiple interesting value opportunities, especially the wider social and environment value for multiple B2U stakeholders that has not been previously identified in the literature. For example, automotive OEMs could profit from various energy services in addition to the revenue from selling the battery asset. When used in grid-related applications, second-life batteries could help deliver more efficient renewable integration and demand reduction, which in the long run, could defer or avoid new power plants and grid upgrade. This would generate considerable economic, social and environmental benefits for utilities, tax-payers, energy users, governments, and everyone in the society, yet is not to be found in any of the current literature on the value of B2U.

The author proposes that in order to better extract value from second-life batteries, it is necessary to consider all three aspects of sustainable value of second-life batteries at the system level. The wider social and environmental benefits could become important sources of value opportunities. This research provides rich empirical data on the sustainable value of B2U for cross-sector stakeholders in the seven case studies that has not been addressed in the literature.

6.5.2 Comprehensive overview of the critical B2U challenges

To date, various B2U challenges have been discussed in the literature from technical, economic or regulatory aspects. However, those studies in isolation present a highly scattered analysis of the challenges that neglects the interdependencies among the factors. Most of the literature simply analyses the challenges of B2U from a single stakeholder's perspective (mostly the upstream stakeholders such as OEMs) or focuses on single aspect (economic or technical challenges) without a comprehensive view of the B2U value chain.

A recent paper by Bräuer (2016) presents a relatively comprehensive list of B2U challenges from the battery life cycle perspective. In this paper, the author also pointed out the lack of contributions from the literature that address challenges on the customer site (Bräuer 2016). Four customer challenges were discussed, namely, customer's risk of acquiring used batteries, proper operation of the battery system, customer's cost-performance ratio and product experience. However, the challenges discussed in most literature lack the support of empirical data. They are based on either the literature or propositions rather than empirical investigations into the real-life challenges encountered by B2U stakeholders.

Based on rich empirical data from the seven case studies, this research has examined the key B2U challenges from a multi-stakeholder's perspective across the value chain, which provides a fresh view on the factors that might impair the potential value of second-life batteries. The empirically-generated results (Figure 5.1) show the current B2U challenges in a more systemic way that has not been addressed in existing literature.

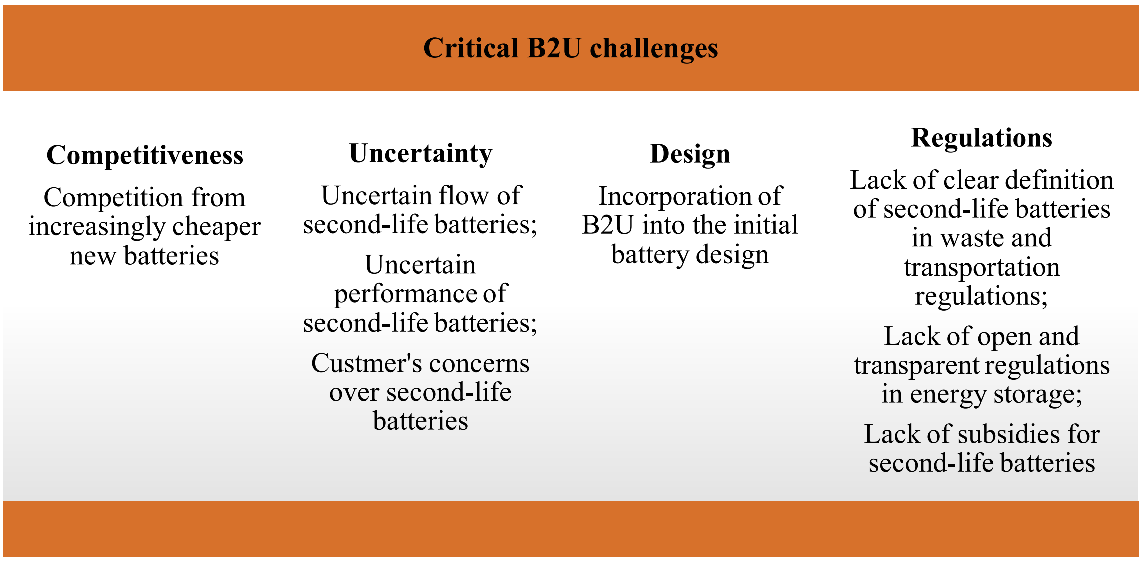

Figure 5.1 Summary of critical B2U challenges

6.5.3 A typology of existing B2U business models

As discussed in Chapter 2, very few studies in the extant literature investigated the value generation from second-life batteries through BMs. Lih et al. (2012) discussed "*optimal business model*" for B2U which was among the first few studies that addressed the BMs of B2U. But this study focused on calculating the profits of the proposed battery leasing model under estimated assumptions instead of actually investigating how value is created and captured from B2U. Interestingly, Bräuer (2016) emphasized the need to design new BMs for B2U and suggessted PSS as a promising approach to countering uncertainties around second-life batteries. This paper addressed the importance of BMs in overcoming the barriers to B2U and offered possible BM solutions, but the BM investigation in the study is very generic and only touches on the concept of PSS to address supplier-customer relationships. Moreover, it is mainly based on propositions with little empirical evidence.

This study proposed a typology of existing B2U BMs through representative B2U cases in the industry (Figure 5.3). The typology is the first of its kind to show how B2U stakeholders are interacting in different ways to create and capture value from second-life batteries. Three categories of B2U BMs were analysed, namely, standard, collaborative and integrative BMs.

The novelty and strength of the typology is that it is generated from rich empirical data rather than simply a proposition or assumption as presented in many literature. Moreover, it disentangles the complex relationships between B2U stakeholders and illustrates the different types of interactions between the key B2U stakeholders based on real-world practices. The strengths and weaknesses of each type of the BMs were also analysed in the case studies. Taken together, this empirically-generated typology provides a comprehensive overview of how B2U firms are currently developing BMs to create and capture value from second-life batteries in different ways, which is absent in the extant literature.

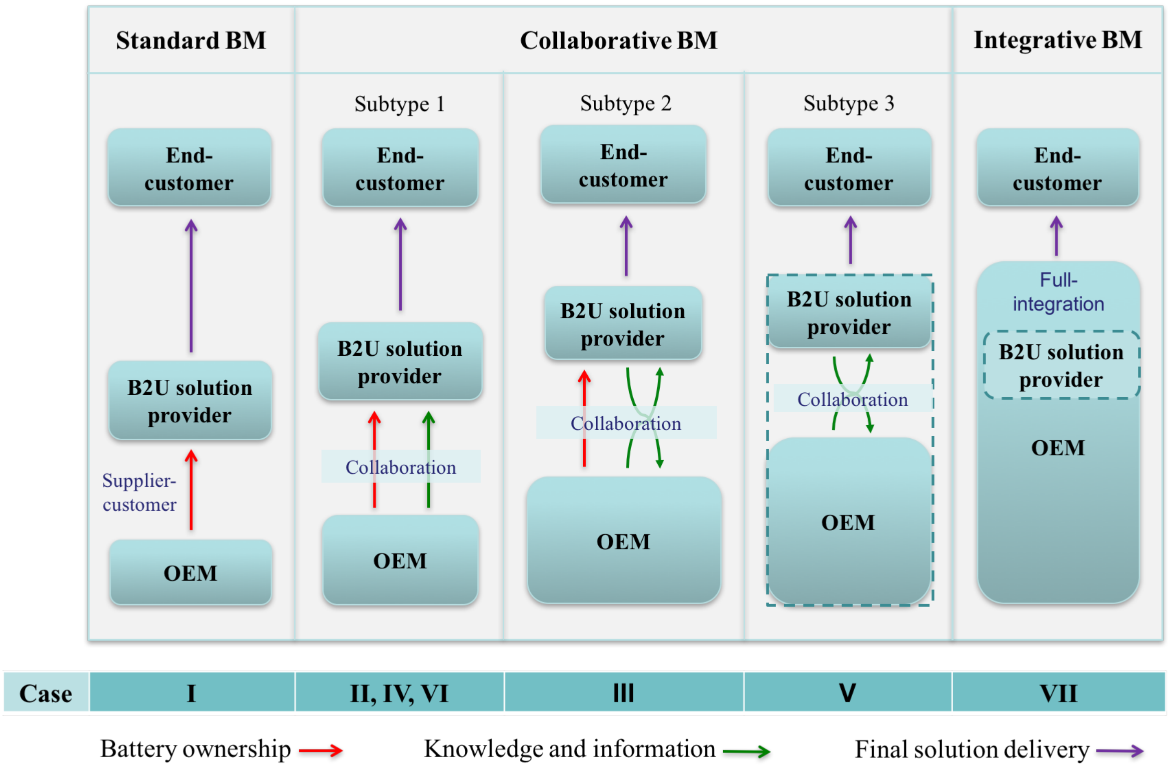

Figure 5.3 Schematic typology of B2U business models:

how cross-sector stakeholders interact to develop business models for second-life batteries

6.5.4 Critical business model design elements for B2U

B2U itself is conceptually regarded as a circular BM of manufacturing firms that integrate EOL issues into their businesses and create value by being more circular. That is why most of the literature address the upstream issues of circular economy. However, adopting those circular concepts will not automatically bring value to the manufacturing firms. Much of the literature talks about remanufacturing, reuse or recycling as circular BMs for manufacturing firms to generate value, but very few go beyond that to explore how to develop BMs for those EOL options. Especially, when it comes to second use, many more cross-sector stakeholders would be involved which will co-determine the value generation. Innovative BMs of specific EOL solutions, for example, repurposing/second use should be carefully designed in order to exploit the potential value of the 'waste'. Many literature on EOL solutions investigated specific technical or economic issues but very few studies explore how firms develop BMs to better generate value from those circular strategies.

This study considers multiple stakeholders along the value chain of B2U to analyse how they interact and develop BMs for second-life batteries, instead of only focusing on the upstream actors, activities and challenges. Based on empirical data, three critical BM design elements, namely, life cycle thinking, system-level design and the shift to services are proposed as helpful aspects for stakeholders to consider to better design their business models for B2U. The three critical BM design elements provide fresh insights to help analyse the value potential of second-life batteries, identify value opportunities, differentiate value propositions and increase the 'overall size of the value pie'. These were not found in any of the B2U business model literature, which the author claims as one of the contributions. Through the case of B2U, this study also contributes to the circular economy literature in terms of providing insights into how to develop BMs to better extract value from EOL strategies.

6.5.5 BMoT as a new perspective to understand the value potential of second-life batteries

Most of the existing BM conceptualizations focus on the firm as a starting point for analysis: how a firm creates value for its customers and entices their customers to pay (Chesbrough & Rosenbloom 2002; Morris et al. 2005; Teece 2010). The firm-centric perspective of BM is helpful in terms of analysing value creation contained in dyadic business relationships (Bankvall et al. 2017). In situations where it is impossible for individual firms to govern all relevant resources and activities, Palo & Tähtinen (2013) suggested that a networked BM is useful to understand the network value and the influence of the network and environment that individual firms are embedded in.

The focus of this study is the value that can be generated from a certain technology (second-life batteries in this case). B2U involves cross-sector stakeholders during different stages of the battery life cycle, where the batteries are owned by different actors. Synthesised from rich empirical data, BMoT is proposed as a new perspective to understand how to improve the total value creation from second-life batteries at the system level and thus, enable greater value creation and capture for multiple stakeholders. This novel perspective of BMs provides new insights into the value of B2U which complements the firm-level and network-level BM analysis.

6.5.6 Contributions to the three streams of literature in sustainability, business models and battery second use

The findings fill the research gap and also contribute to the three broader streams of literature in sustainability, business models and B2U. In the extant B2U literature, little is known about the realities of how firms extract value from second-life batteries. There are a few studies on the BMs of B2U but they only touched on the concept of BM and offered little insights into the potential value of B2U and how the value could be realized. The lack of research on the BM logic informed by empirical evidence would make it difficult to understand the value potential of B2U. The findings of this research contribute to the B2U literature by providing empirical insights into the existing B2U value system and improving understanding of the BM logic that delivers sustainable value from B2U.

The findings contribute to the BM literature by presenting the value exchange logic of repurposing and the increasing importance of service in BMs. Second-life or repurposing is gaining increasing attention in the BM literature as being an approach to a more sustainable BM. However, no literature has investigated the BMs that are specifically optimized for second-life. The empirically-generated typology of existing B2U business models provides a fresh insight into how value is currently created and captured from repurposing a second-life of a product. The three critical BM design elements (life cycle thinking, system-level design and shift to services) provides helpful insights into better designing BMs of second-life. The findings thus also contribute to the circular business model literature by extending the current discussion on what constitutes a circular business model to how to make business models more circular. Moreover, Business Model of a Technology (BMoT) provides a new perspective that could be complementary to the traditional firm-centric view of a BM to help better understand the potential value of a specific technology and how to maximize the total value creation from that technology at the system level.

The findings also contribute to the sustainability literature. The literature on industrial ecology and circular economy is making it clear that second-life is increasingly important in the future. Actually, the literature has primarily taken second-life as a technical challenge so there are lots of research on the technical aspects of second-life (e.g. technical feasibilities or design of repurposing a second-life for a product). The contribution to the sustainability literature is, at one level, not new to sustainability, for example, the concepts of sustainable value analysis and life cycle thinking. However, this research adds to the sustainability literature by applying the core sustainability concepts into the specific context of B2U thereby delivering some new insights that in turn enrich those concepts. For example, the life cycle thinking proposed in this study extends beyond one life of a product to include multiple lives: the EOL of a product could be the start of another life cycle in a different application for example.

6.6 Practical implications: the future of B2U

B2U is an EOL option for companies to move towards being more circular. However, few BMs presented are circular because the system they are part of does not allow them to be. B2U is still at its embryonic stage with lots of uncertainties and challenges. Compared with new batteries, one of the biggest concerns for B2U is the uncertainty of the battery performance in different second use applications. To address this uncertainty and help B2U stakeholders better extract value from second-life batteries, innovative BMs supported by big data and sophisticated IT systems are essential. Since the battery value depends on various factors during different stages of the battery life cycle, for example, how they were used in the EVs, how they are repurposed and how they will be used in second-life storage applications, key data need to be collected from cross-sector stakeholders and managed in a way that allows batteries to achieve their optimal value.

This study has practical implications for the future of B2U. The life cycle thinking, system-level design and service concepts, as well as the technology-centric perspective of BMs addressed in this research could help B2U practitioners better design BMs in a systemic way that help extract more system value from second-life batteries. In the future, B2U could be part of a bigger "smart energy" system and innovative BMs are needed to increase the value of the system. For example, inspired by the findings of this research is a case study of the future of B2U – the response to an international competition on the future of second-life batteries (Figure 6.3). The International Competition on Second Life for Retired Batteries from Electric Vehicles was hosted by the Environment Bureau of the Government of Hong Kong Special Administrative Region in 2017 to help find innovative ideas for retired EV batteries. The author proposed "Maximising the Value of Second-life Batteries for a Smarter Demand-Side Management in Hong Kong: the Cloud Energy Storage System Based on Big Data" and won the "Best Originality Award" as well as the "First Runner-up". The idea is to deploy grid-sensitive, smartly managed second-life battery system as part of the Cloud Energy Storage that optimise the total energy value, namely, the value of cell management, value of building management, value of demand management as well as value of supply management. This would be achieved through managing the big data shared by various B2U stakeholders and managed through the cloud that connects all the actors.

This competition is the first of its kind which also shows that B2U is being brought into the policy agenda. Regulations on EVs and the electricity market (e.g. electricity deregulation) are essential for establishing the markets for second-life batteries and bring the whole system into operation catalysis, which is indispensable for optimising the value of B2U.

Environment Bureau
The Government of the Hong Kong Special Administrative Region

Submission for the International Competition on Second Life for Retired Batteries from Electric Vehicles

International Competition on Second Life for Retired Batteries from Electric Vehicles

2nd Life for EV Battery

Maximising the Value of Second-life Batteries for a Smarter Demand-Side Management in Hong Kong: the Cloud Energy Storage System Based on Big Data

ABSTRACT

In Hong Kong, the Government's promotion of electric vehicles (EVs) has led to a boom of EV popularity in recent years. The battery, which is the single most expensive part of an EV, normally retires from the cars after 8 to 10 years. The retired batteries could still retain 70 to 80 percent of the initial capacity which could be further utilised in various post-vehicle applications. The somewhat degraded but still capable batteries could provide a flexible and cost-effective storage solution for a smarter demand-side management (DSM) in Hong Kong. The idea proposed is to deploy grid-sensitive, smartly managed second-life batteries as part of the "Cloud Energy Storage" for DSM based on big data. Through a smart algorithm design, second-life batteries are intelligently controlled as part of the grid-connected, community-wide energy management system that make smart choices in response to the grid signals. The originality of the idea lies in the management of the big data shared by various stakeholders and the combination of potential applications e.g. photovoltaic (PV) self-consumption, demand response and EV charging, including shifting between these in a smarter way so that the value of the electricity stored in the batteries could be maximised. The idea proposed is viable because it is a novel combination of known technologies and concepts which are practical and safe in real-life applications. The environmental implications of the proposed concept, e.g. a cleaner transportation and electricity mix, more efficient operation of the power plants and the avoidance of inefficient peaking plants through smarter DSM, are enormous in reducing carbon emissions and air pollution. The regulation as well as the establishment of the electricity trading market and the relevant market mechanisms are essential to the successful deployment of second-life batteries for DSM.

Figure 6.3 Abstract of the author's response to the International Competition on Second Life for Retired Batteries from Electric Vehicles hosted by the Hong Kong Environment Bureau

7 Conclusions

The final chapter draws together the conclusions of this research. The key contributions to knowledge and practice made through this study are summarised in Section 7.1. In Section 7.2, the limitations of this research are explained. Opportunities for future research are then presented in Section 7.3. The chapter ends in Section 7.4 with final words that conclude this thesis.

7.1 Contributions

The main outcome of the research is an increased understanding of the value of B2U for multiple stakeholders. Through rich empirical evidence from a series of seven case studies into the B2U business models, this study contributes to both knowledge and practice. The key contributions to knowledge are summarised as follows.

- The sustainable value of second-life batteries provides a comprehensive view of the potential value of B2U (see Section 6.5.1, Section 5.1 and Chapter 4);
- The critical B2U challenges from a multi-stakeholder's perspective across the value chain are identified from empirical case studies that present a fresh overview of the key factors that might impair the potential value of second-life batteries (see Section 6.5.2 and Section 5.2);
- An empirically-generated typology of existing B2U business models is presented that shows how B2U stakeholders are interacting in different ways to create and capture value from second-life batteries (see Section 6.5.3 and Section 5.3);
- Three critical BM design elements, namely, life cycle thinking, system-level design and the shift to services are drawn from the analysis of current BMs and proposed as helpful aspects for B2U stakeholders to consider to better design their BMs for second-life batteries (see Section 6.5.4 and Section 6.2);
- BMoT is proposed as a new perspective to understand the value potential of second-life batteries and how to maximise the total value creation from B2U at the system level

(see Section 6.5.5 and Section 6.3).

All the theoretical contributions listed above are not systematically addressed in the current literature. Altogether, the contributions help increase our understanding of: a) the potential value of second-life batteries and the challenges that might prevent the value extraction; b) current BMs for second-life batteries; and c) the incorporation of sustainability into BMs that helps achieve the potential value of second-life batteries, which provide insights into answering the research question:

How could firms develop battery second use business models based on sustainability concepts to achieve the potential value of second-life batteries?

The research question has been answered through: a) conducting sustainable value analysis of B2U that help understand the potential value of second-life batteries; b) identifying critical B2U challenges that might impair the value of second-life batteries; c) offering a B2U business model typology that shows how B2U stakeholders are interacting in different ways to create and capture value from second-life batteries; d) identifying three critical BM design elements that draw on key sustainability concepts to help design BM that better extract value; and e) creating BMoT as a new perspective to understand the value potential of second-life batteries and how to maximise the total value creation from B2U at the system level. Taken together, this study answers the original research question and contributes to the fields of sustainability, business models and B2U.

This research also provides contributions and implications for industrial practitioners. The sustainable value of second-life batteries proposed can help B2U firms better evaluate the overall benefits of B2U and identify potential value opportunities. The key B2U challenges identified from the empirical cases can inform practitioners of the factors they need to consider in designing their BMs that help overcome the barriers to extracting value. The empirically-generated typology of existing B2U business models has the potential to inspire practitioners to be innovative with their B2U business models and experiment with different models according to their own situations. The three critical BM design elements could help practitioners better design their BMs to generate and capture more value from second-life batteries. Finally, BMoT offers a new perspective for practitioners to understand the potential value of second-life batteries at the system level. This new perspective of BMs has the potential to inspire practitioners to jump out of the firm boundary and think at the system level to optimise the total value creation which also enables greater value capture for individual stakeholders.

7.2 Limitations

This research has limitations due to the limited scope that a PhD study can cover. One limitation is the generalisability of the findings over time. In the nascent stage of B2U, there are only a few B2U examples that could provide empirical evidence to study the BMs of second-life batteries. Also, the seven B2U business model case studies are at an early stage of commercialisation and they are changing quickly in response to learning, which might limit their usefulness in the future. However, the author has attempted to cover all the existing B2U commercialisation cases, including not only B2U business models from different companies, but also different models from the same company. Future research should follow the development of the B2U industry and investigate emerging B2U business models over time.

Other limitations include the scope of the study. This research investigated the various B2U business models developed and discussed the factors that influence business model selection, but did not cover a detailed mapping between various business models and the determining factors. This is because at the early stage of B2U, BMs of second-life batteries are still emerging and evolving in response to shifting contexts and emerging factors might continuously influence how companies design or select business models for B2U. Future research should investigate the BM selection criteria which would greatly help B2U stakeholders design their BMs for second-life batteries.

7.3 Future research

Limitations bring opportunities for future research. First, the development of the B2U industry should be continuously followed to carry out more case studies to make the results more generalisable and robust. With more stakeholders joining the B2U system, interviews with emerging stakeholders (e.g. start-ups) can be included to enrich this study.

Second, the findings suggest that companies are now experimenting with different business models for B2U and the current business models might change with the maturing of the industry. Opportunities exist that the research can be followed up to conduct a longitudinal study, exploring how B2U business models change with the development of the B2U system.

Third, the selection of B2U business models depends on many factors. A mapping between the various BMs and a series of factors could provide a BM selection criteria that help B2U stakeholders better design and evaluate their B2U business models.

7.4 Final words

Throughout the PhD study, this research on the business models of B2U has drawn increasing attention from academics and practitioners alike. When the research project started, there were few discussions on this topic and very few companies had concrete business plans for B2U. Most of them were discussing the technical issues related to B2U and their understanding of the value of second-life batteries was limited. During the research, various companies have launched their B2U solutions and started to extract value from those retired batteries. The author is delighted to see the fast development of B2U but is also aware of the challenges facing this nascent industry. It is the author's hope that more stakeholders take up these new opportunities to create more value from second-life batteries and that governments take measures to support and guide the development of B2U.

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Appendix A. List of interviews

Company	Stakeholder role	Region	Interviewee's position	Reference code	Time (mins)
Company A	OEM	Japan	Manager, Battery Business Unit; General Manager, EV Operations Dept.	O-1-1	125
		North America	General Manager	O-1-2	127
		Europe	General Manager, Zero Emission Strategy; Manager, V2G and Stationary Storage; Expert Leader, Technology Planning Dept., Advanced Engineering Div.	O-1-3	175
Company B	Energy storage/ B2U system provider	California	CEO and Co-founder	E-1	132
Company C	Lifecycle management	US	President and Founder	L-1	38
Company D	B2U joint venture	Japan	President	BJV-1	105
			General Manager, Planning Div., General Manager, R&D Div.		131
Company E	Energy storage/	California	COO	E-2	63

	B2U system provider				
Company F	Power/energy management	Europe	Vice President of EMEA Marketing	E-3	50
Company G	OEM	North America	Manager, Connected eMobility	O-2-1	75
		Germany	Program Leader for Battery 2nd Life; Head of Development Stationary Storage Systems	O-2-2	128
Company I	Energy storage	Germany	Managing Director	E-4	206
Company J	OEM	France	Program Manager, Energy Services	O-3	57
Company L	OEM	Japan	Project General Manger, New Business Planning Div.; Project Manager, Environmental Affairs Div.; Group Manager, Planning Dept.	O-4	106
Out-of-case: Supplementary interviews					
Company M	OEM	Japan	Industrial-Use Battery Business Team, Environmental Energy Business Dept.; Engineering Strategy Dept.	O-5	94
Company N	Electricity utility	Japan	eMobility Team, Research Institute	EU-1	134
Company O	Power and energy management	Japan	CEO and President	E-5	91

Company P	Safety consulting and certification	US	Principal Engineer Director, Energy & Power Technologies	S-1	28
Company Q	Energy expert	US	Senior Associate, Advanced Transportation	EXP-1	50
Company R	Energy storage	Germany	Project Leader, Energy Storage System	E-6	59
Company S	OEM	China	Director, JR Design Centre, Technology Dept.	O-7	135
Company T	Battery manufacturer	China	Senior Engineer, R&D Dept.	BO-1	75
Company V	Battery recycling	China	General Manager; Technical Director, R&D Dept.	BR-1	58
University of Waterloo	Sustainability management expert	Canada	Associate Professor, School of Environment, Enterprise and Development	EXP-2	50
University of Tokyo	Energy expert	Japan	Project Associate Professor, Systems Innovation	EXP-3	82

Appendix B. Interview questionnaire sample

Below is an example questionnaire sent to Company F, a power management company in Case III. The questionnaires were adapted according to the type of company interviewed, but remained as similar as possible.

Interview questions

Vice President of EMEA Marketing, Company F, 13/01/2017

Introduction

1. Please briefly introduce Company F and your role at the company.
2. What is the purposes/motivations for company F to develop second-life batteries?
3. What are the benefits of developing second-life batteries?
4. What challenges have you experienced and expected for second-life batteries?

Business models

5. How do you describe your business model for second-life batteries?
6. What is the value proposition offered to your customers?
7. During the development of second-life batteries, what activities are conducted by Company A and F (Company A's OEM partner)? How was the product/service developed?
8. How do you describe your relationship with Company A (the OEM partner)?
9. What is the role of Company F and your partners in the value chain? How is Company A's engagement in B2U?
10. How do your profit from the battery second use business (what are your revenue streams)?
11. What is the battery recycling liability at the very end of the battery life?

Market and regional context

12. What are the competitive advantages of your company to develop second-life batteries?
13. With new battery cost decreasing, how could second-life batteries compete with new batteries? Will they differentiate in business models from new batteries?
14. What are the factors (regulations, market etc.) that influence and shape your business model for second-life batteries?

Concluding question

15. Is there anything else you would like to discuss or add?

Thank you!